Vibration Analysis

Vibration Analysis

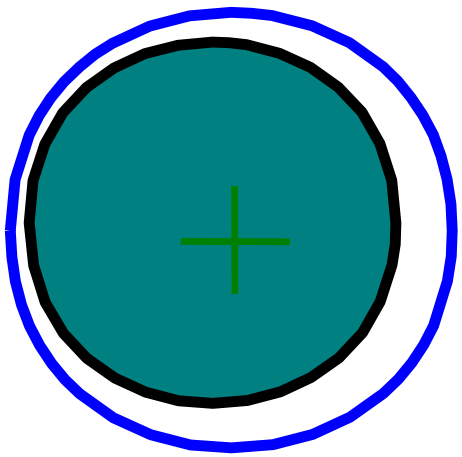
"Of all the parameters that can be measured non-intrusively in industry today, the one containing the most information is the vibration signature."

Art Crawford

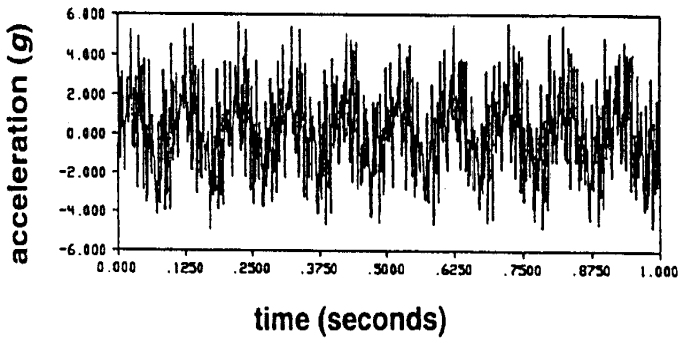
What is Vibration?

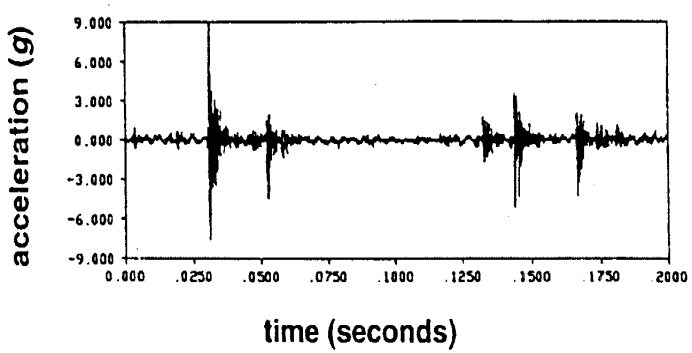
- Vibration is the motion of a body about a reference point caused by an undesirable mechanical force.

Shaft vibration caused by the shaft moving about the centerline of a journal bearing.



Basic Terminology in Vibration

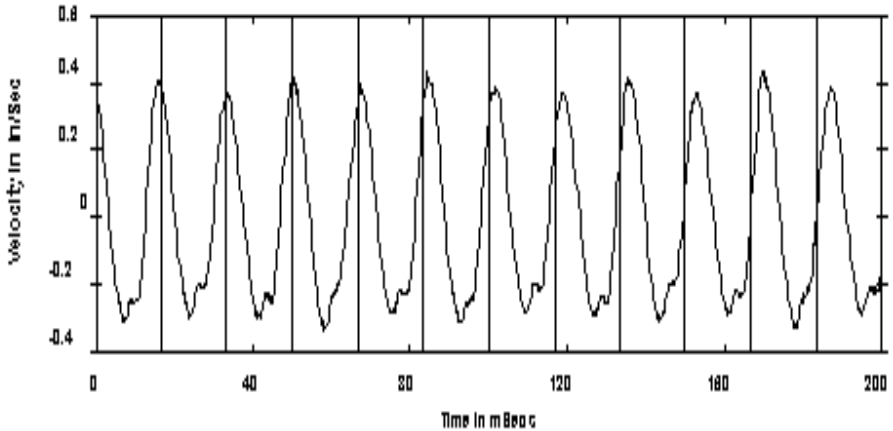


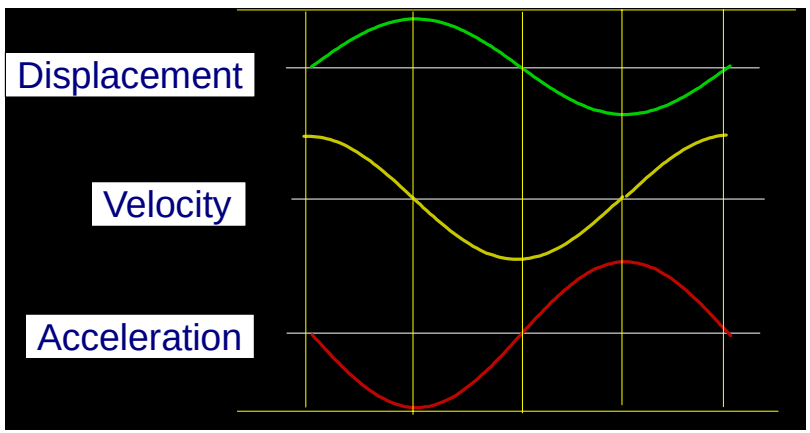


- Vibration is a continuous, random or periodic motion of an object
- or transient “impact” event of short time duration
- Caused by either a man-made, natural excitation of a structure, and mechanical faults .
  - Vibration institute

Basic Terminology in Vibration

- **Time Waveform**
  How does the vibration change over time
- **Amplitude**
  How big/severe is the vibration?
- **Frequency**
  How rapidly does the vibration change?
- **Phase**
  What is the delay between events?





D = max

V = 0

A = max

D = 0

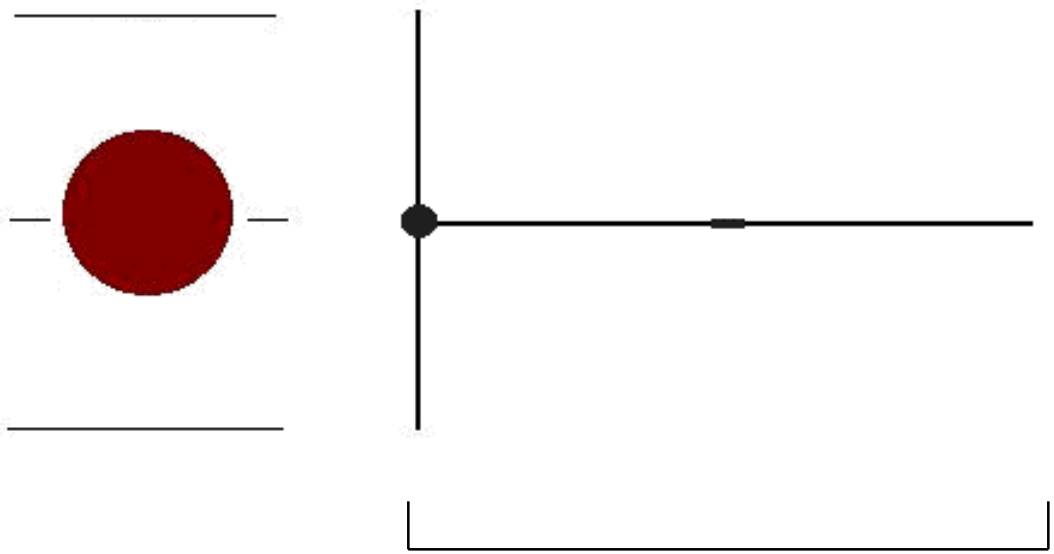
V = max

A = 0

D = max

V = 0

A = max



1 period, T

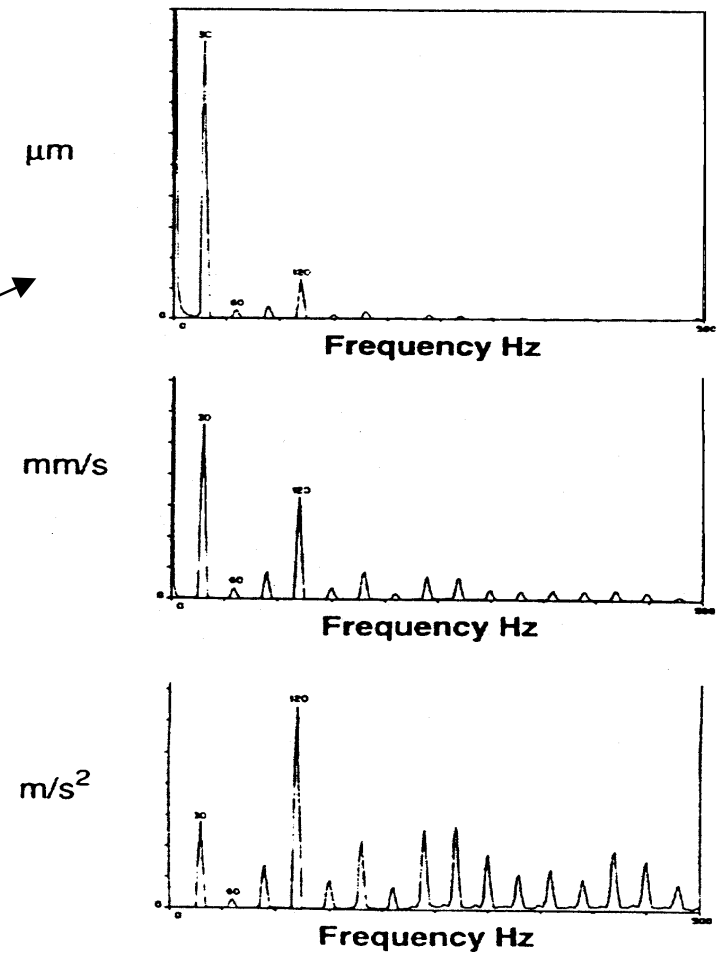
Frequency (f) = 1 / T

How Vibration is measured & described

- Displacement (mils, micron)
  - distance of an object from its reference position
- Velocity (ips, mm/s)
  - the rate of change of displacement with time
- Acceleration (g, mm/s^2, Inch/s^2)
  - the rate of change of velocity with time
  - g = 9.807m/ s^2

Displacement, Velocity and Acceleration – on a Same Vibrating Machine

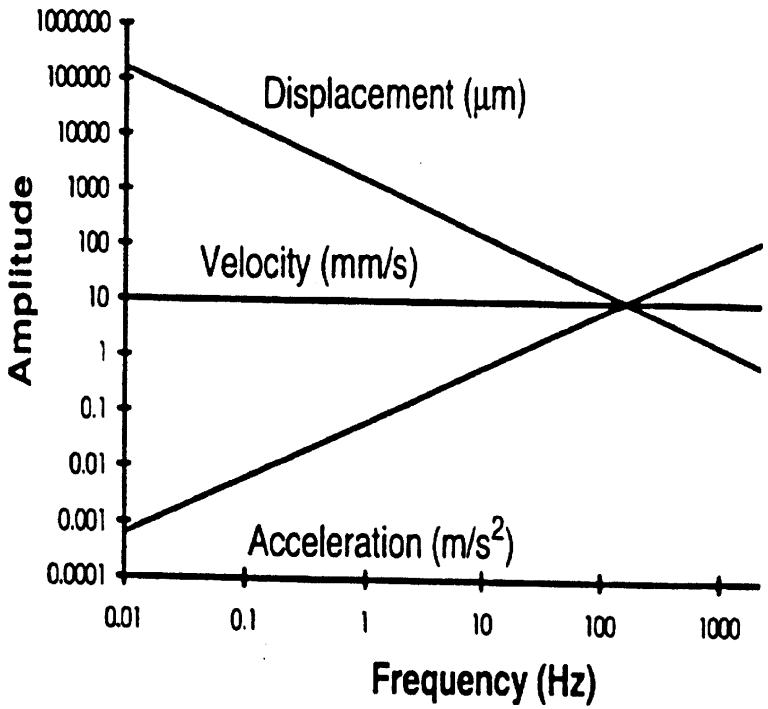
- Peaks of graphs are at increments of 30Hz (i.e.. 0, 30Hz, 60Hz, 90Hz…)
  - Displacement (mm)
    - Proximity Probe
  - Velocity (mm/s)
    - Velocity Pickup
  - Acceleration (m/s^2)
    - Accelerometer



Relation between Displacement, Velocity, Acceleration

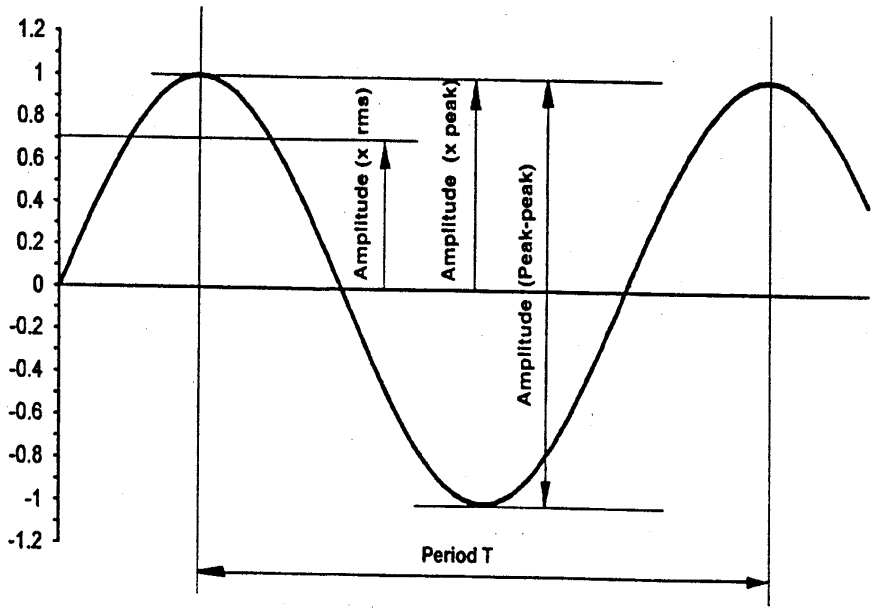
- Displacement
  - A sin(**w** t)
- Velocity
  - A **w** cos(**w** t)
- Acceleration
  - -A **w²** sin(**w** t)

- Where
  - **w=**radian frequency=2**p**f



How vibration is measured & described

- **Peak – to – Peak**
  - Commonly used for displacement measurement
  - Equal to 2x Peak
- **Peak (zero to peak)**
  - Can be used to express Velocity & Acceleration (US)
- **RMS (root mean square)**
  - Equal to 0.707 x peak
  - Can be use to express Velocity & Acceleration (Europe)



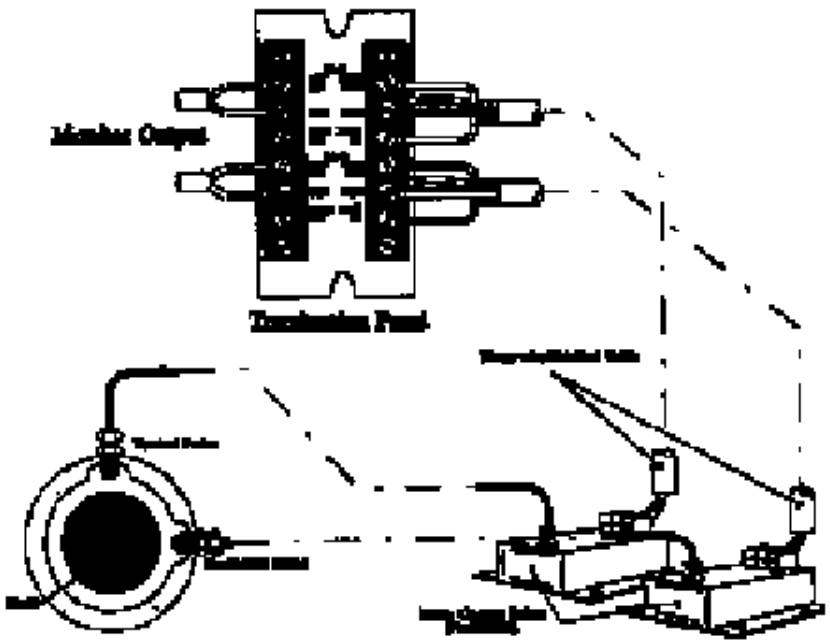
$$w = 2 \cdot \pi \cdot f$$
$$T = 1/f$$
$$X_{rms} = X_{peak} / \sqrt{2} = 0{,}707 \cdot X_{peak}$$

Vibration Transducer

- Displacement transducers:
  - *typically used for shaft relative movement at low frequencies*
- Velocity transducers
  - *commonly used for low to intermediate frequency applications, where velocity believed to give best guide to vibration severity*
  - *best to measure velocity with an accelerometer using electronic integration*
- Accelerometers:
  - *best for high frequency, such as bearing impacting, high speed gear & blading problems*
  - *transducer of choice for industrial applications*

Vibration Transducer

Proximity Probe

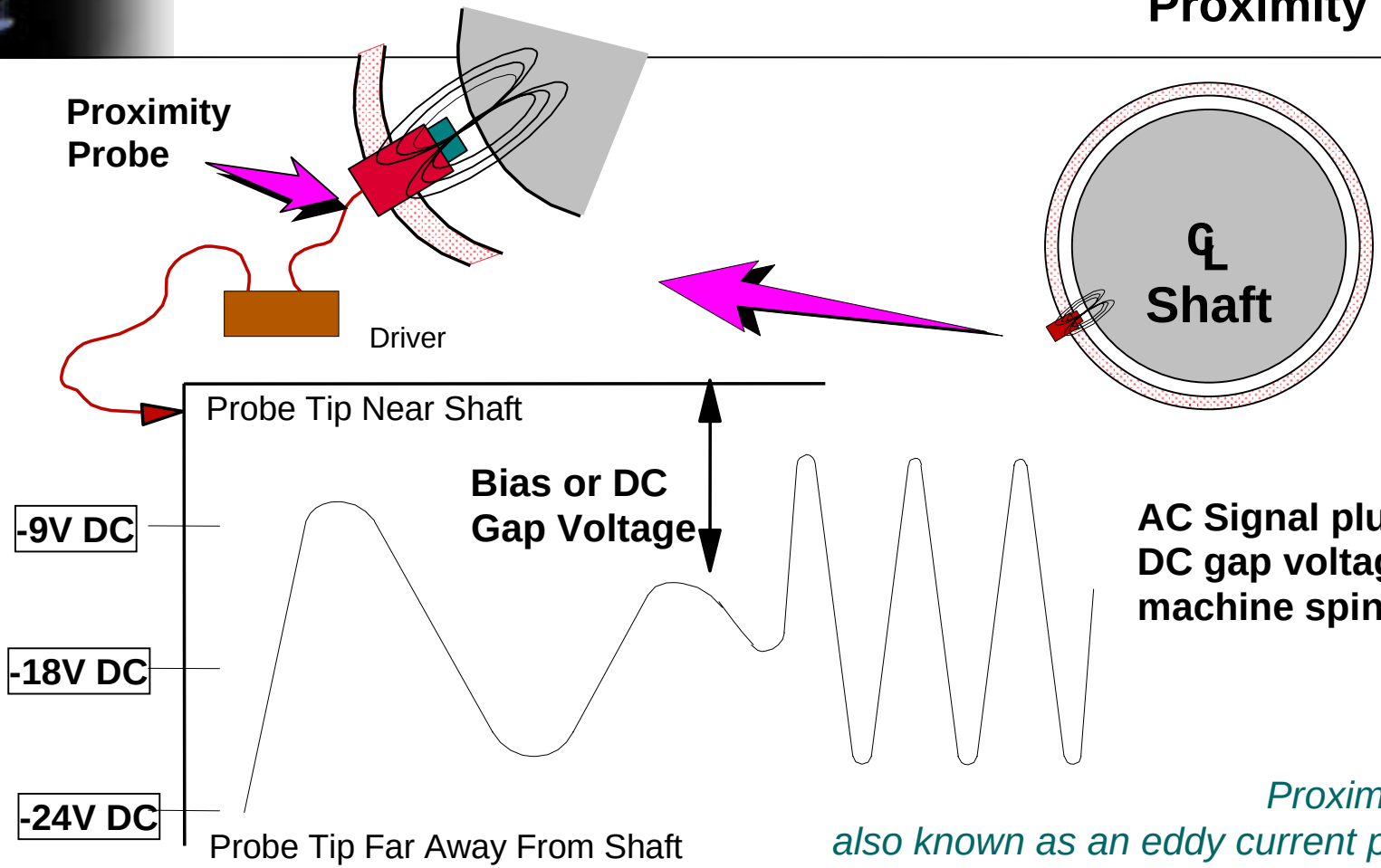


Radial X & Y Installation

- Measures *relative displacement* between probe tip and rotating shaft
- Useful on machines with high case to rotor weight ratio (e.g. steam turbines)
- Usually already installed as *OEM* equipment
- Limited frequency range due to run-out
- *0 to 1000 Hz* (0 to 60,000 CPM) typical
- *Requires special power supply*/signal conditioner and cables

Application & Data Representation

Proximity Probe

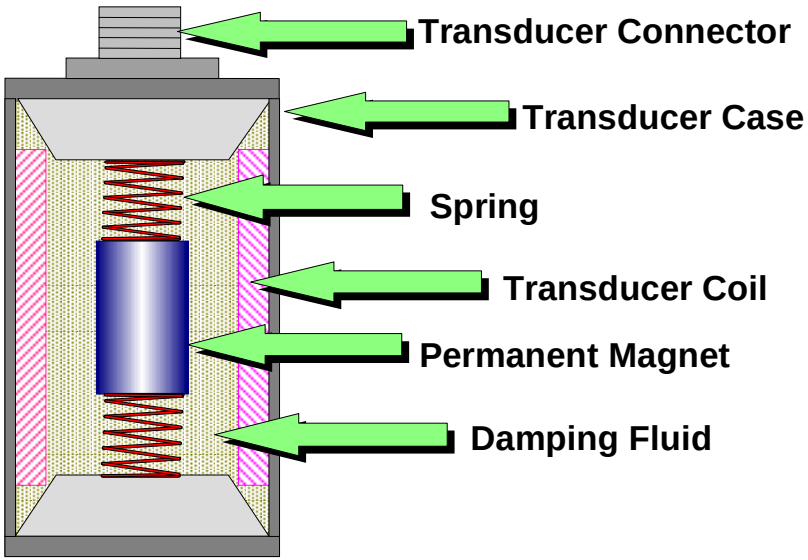


AC Signal plus the DC gap voltage for machine spin-up

Proximity Probe, also known as an eddy current probe, has both AC and DC signal components. AC signal represents vibration; DC average clearance, plus offset.

Vibration Transducer

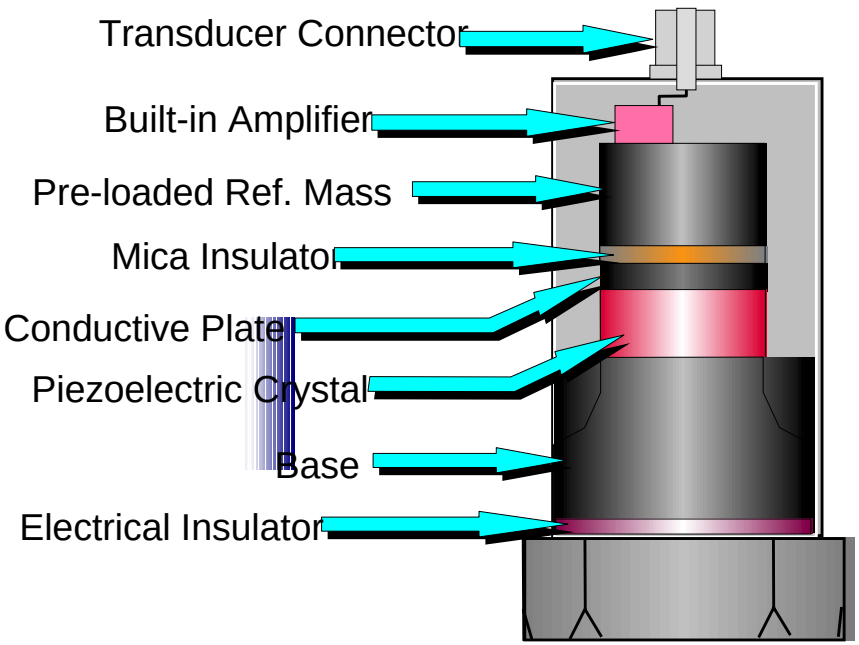
Velocity Pick-up



- Seismic transducer *works well where there is significant casing vibration*
- Gives velocity signal directly
- Self-generating, *no power required*
- May have good signal-to-noise ratio, but limited frequency range *(10 - 2000 Hz)*
- Tend to be relatively large, heavy & expensive.
- Transducers must be mounted horizontally to obtain the best results
- Calibration may shift due to wear and temperature fluctuations (due to damping)

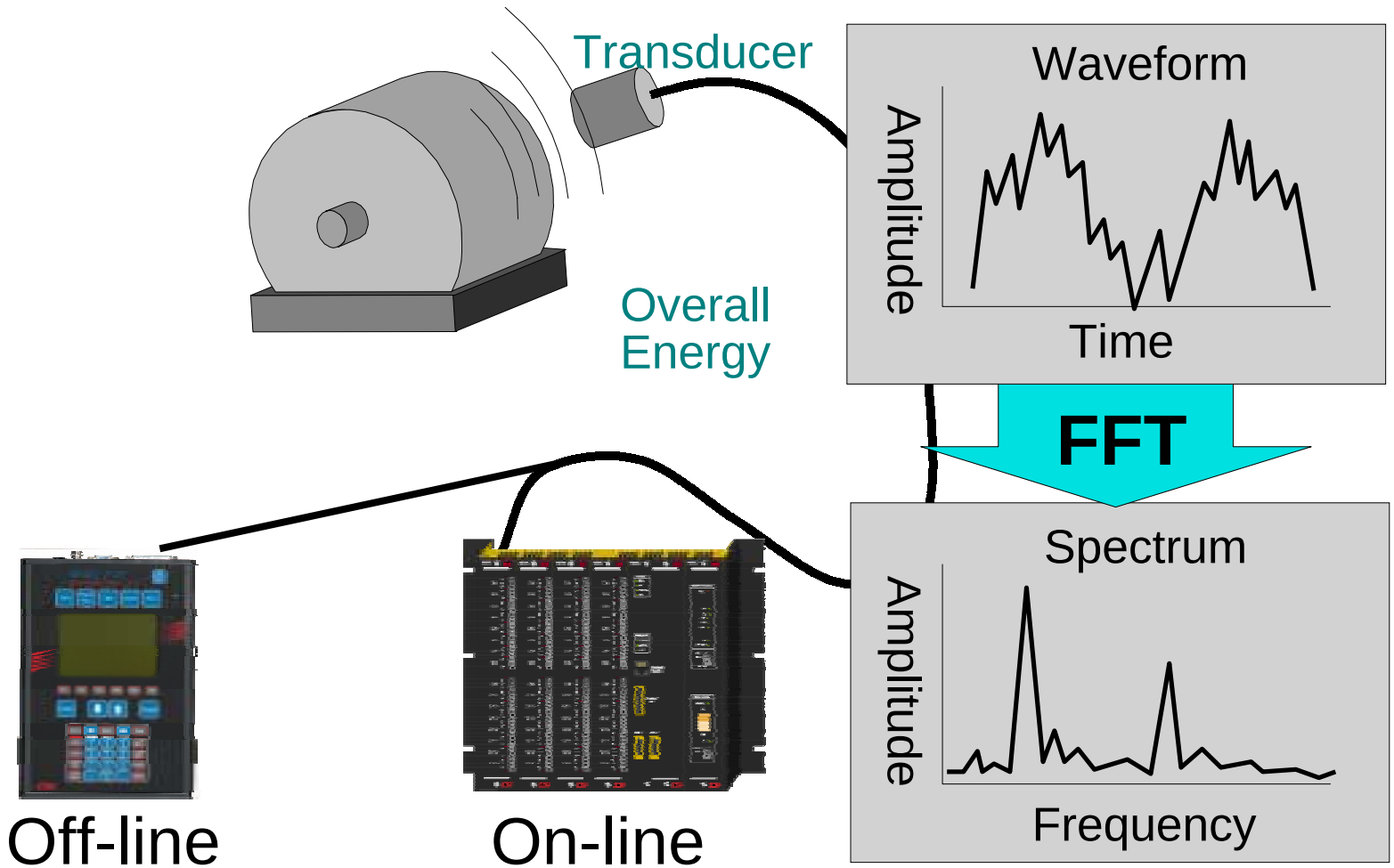
Vibration Transducer

Accelerometer

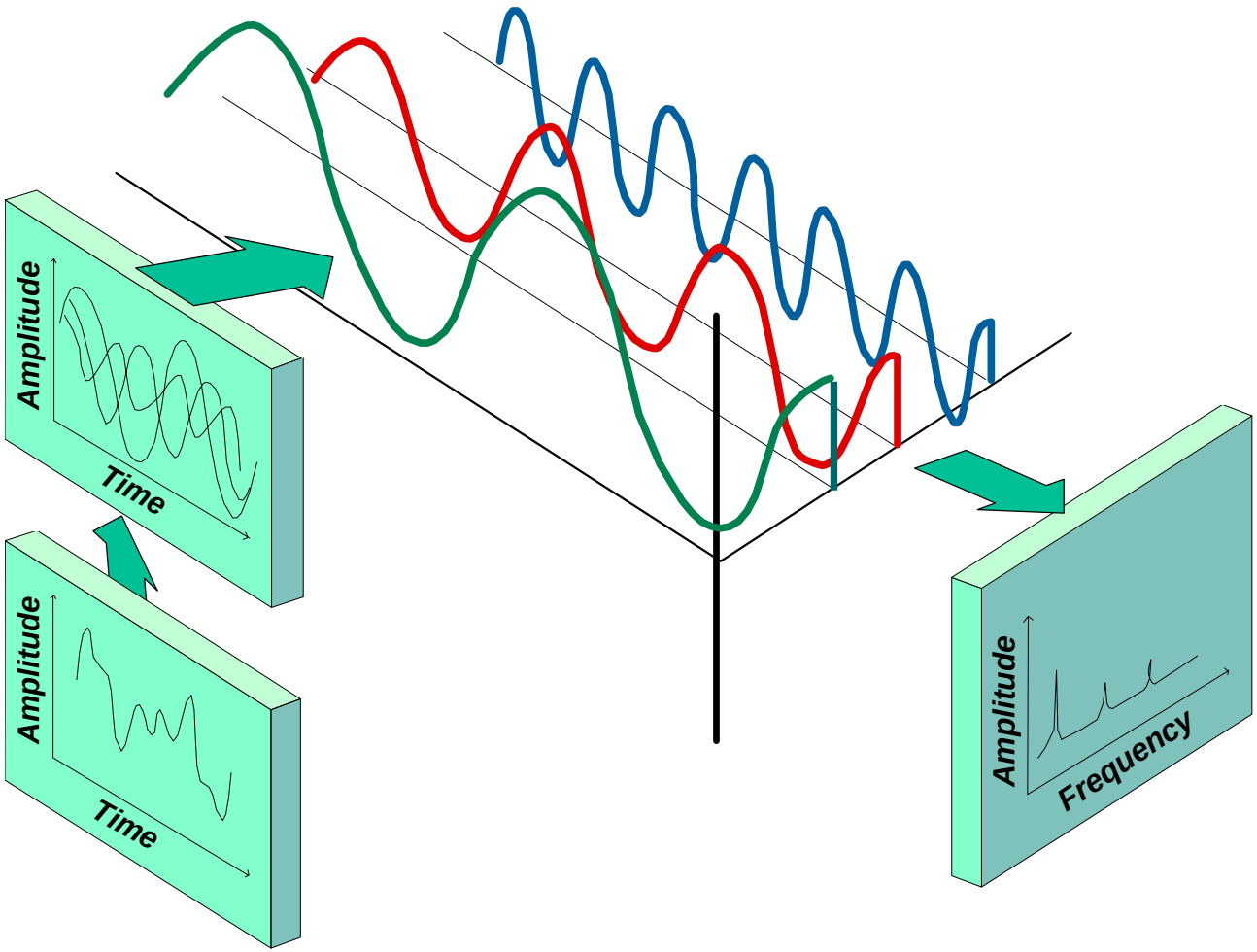


- The transducer of choice in industry today
- Very wide frequency range possible
  - from 0 to 20,000 Hz (different transducers!)
  - typically *2 to 15 kHz* (120 to 900,000 CPM)
- Extremely rugged, no moving parts
- Relatively small and lightweight
- Easy mount for permanent or intermittent use *(stud, adhesive, magnet, hand-held)*
- *Requires constant current power supply for built-in amplifier* (some need external amps)
- Signal output is acceleration

Signal Data Acquisition



FFT Signal Processing



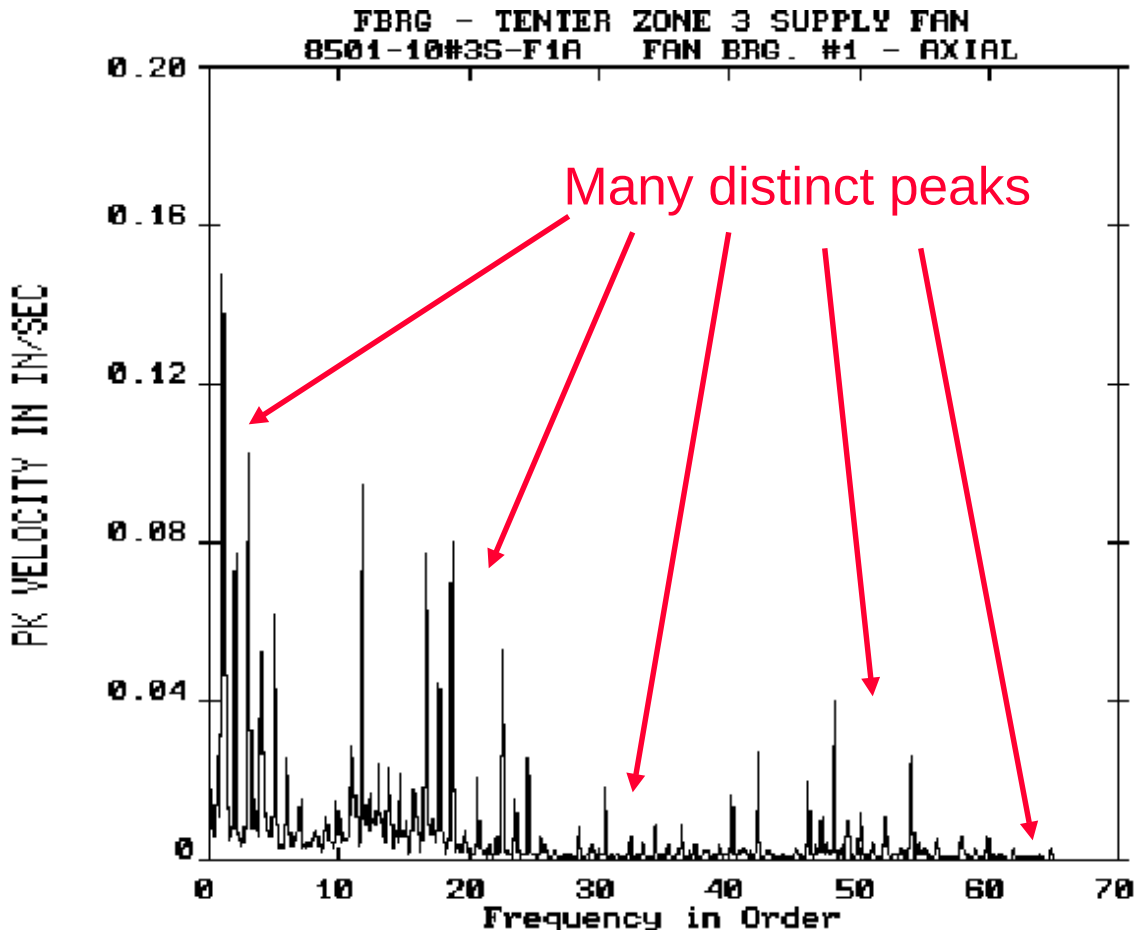
Single Channel Vibration

Machine Fault Diagnosis

Three Rules of Diagnosis

- Each machine fault generates a specific vibration pattern
- The frequency of the vibration is determined by the machine geometry and operating speed
- A single vibration measurement provides information about multiple components

A Typical FFT Spectrum



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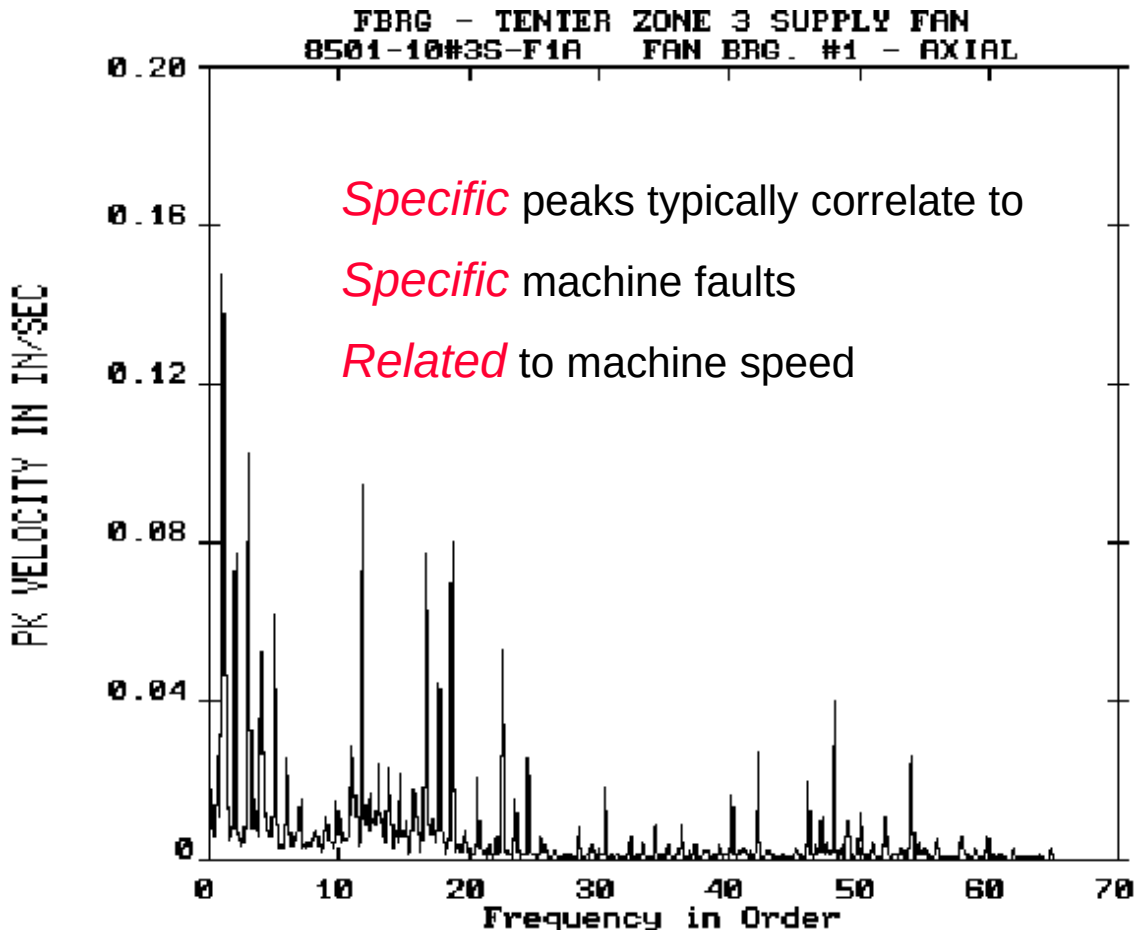


Specific peaks typically correlate to

Specific machine faults

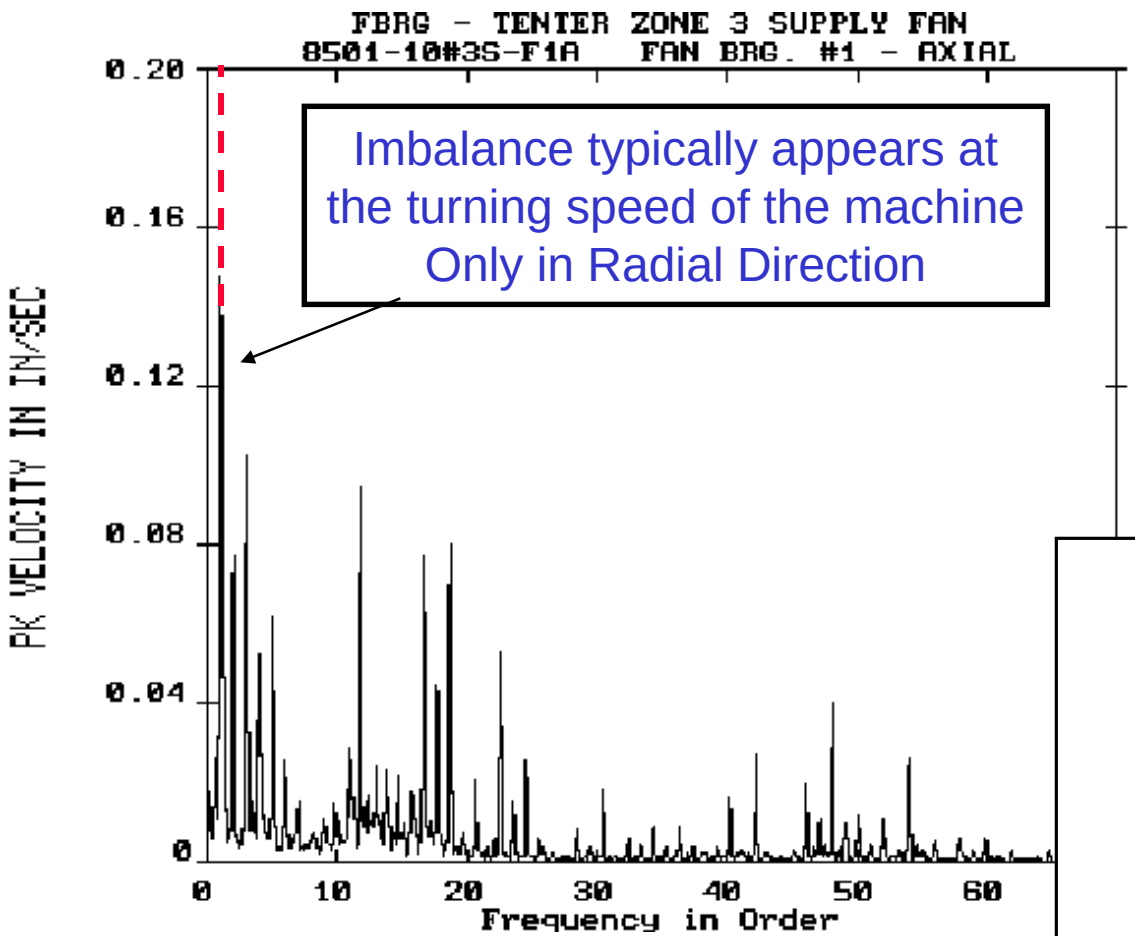
Related to machine speed

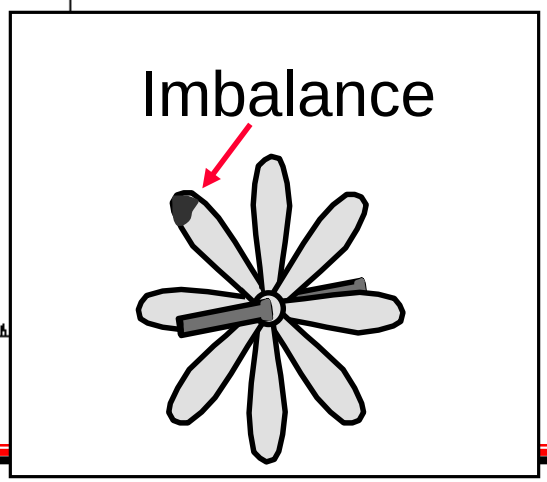
Typical Machinery Problems

- Unbalance → 40%
- Misalignment → 20%
- Resonance → 20%
- RE Bearing
- Sleeve Bearing
- Gear Problem → 20%
- Motor Electrical
- Cavitations
- Vane pass
- Etc.

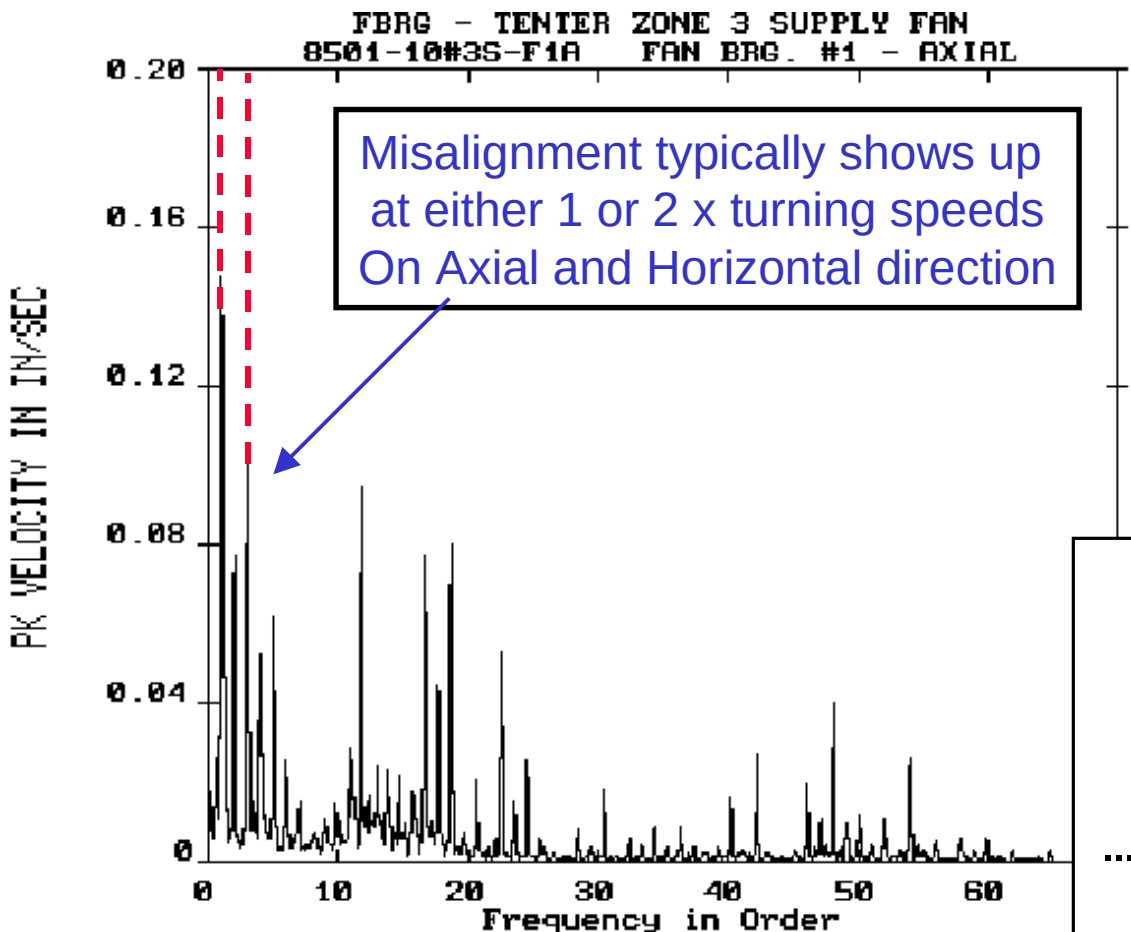
Ralph T Buscarello
Update International

Unbalance

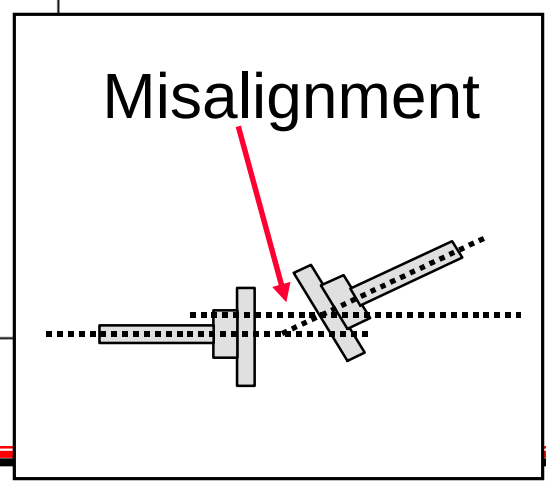

FBRG - TENTER ZONE 3 SUPPLY FAN
8501-10#3S-F1A FAN BRG. #1 - AXIAL
PK VELOCITY IN IN/SEC
0.20
0.16
0.12
0.08
0.04
0
0
10
20
30
40
50
60
Frequency in Order
Imbalance typically appears at the turning speed of the machine Only in Radial Direction


Imbalance

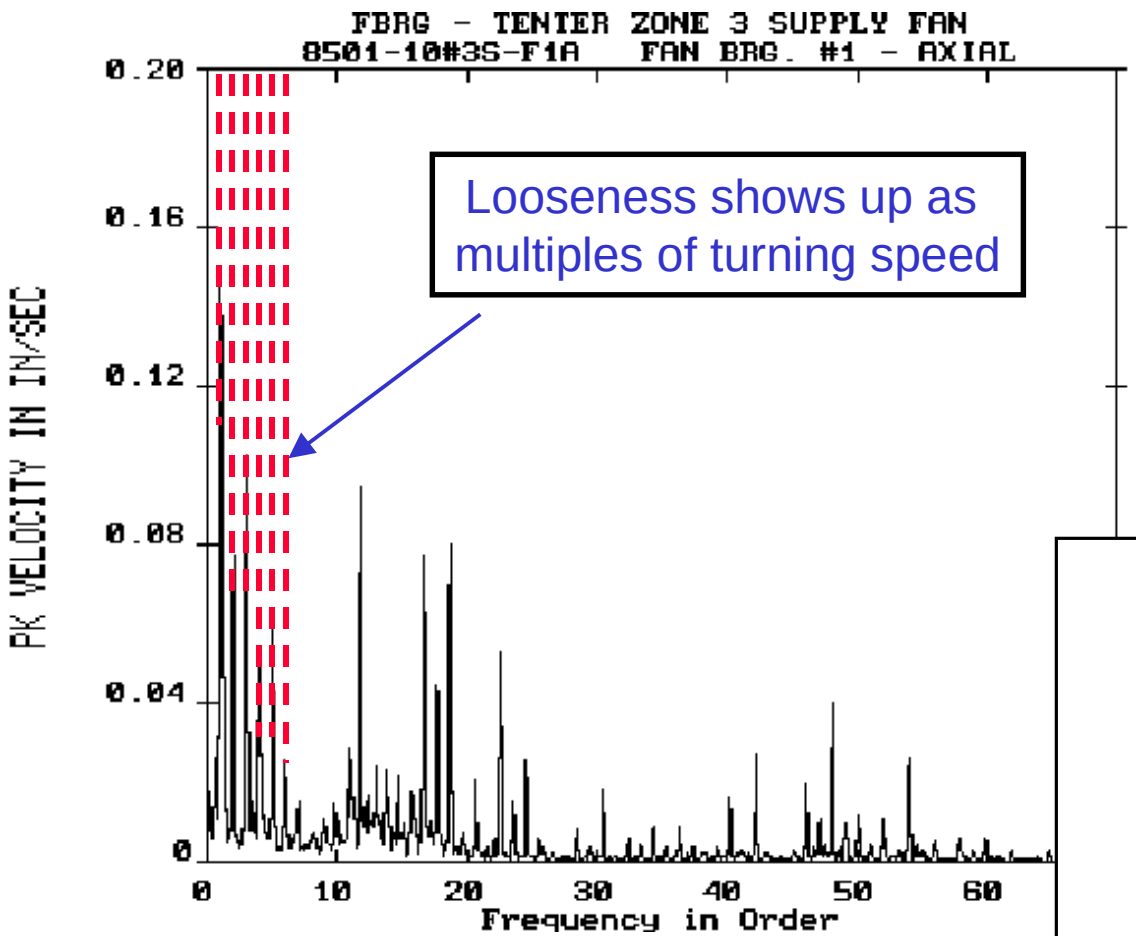
Misalignment

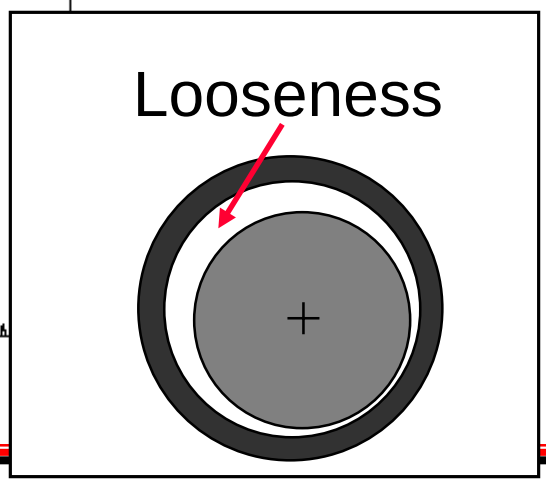


Misalignment typically shows up at either 1 or 2 x turning speeds On Axial and Horizontal direction

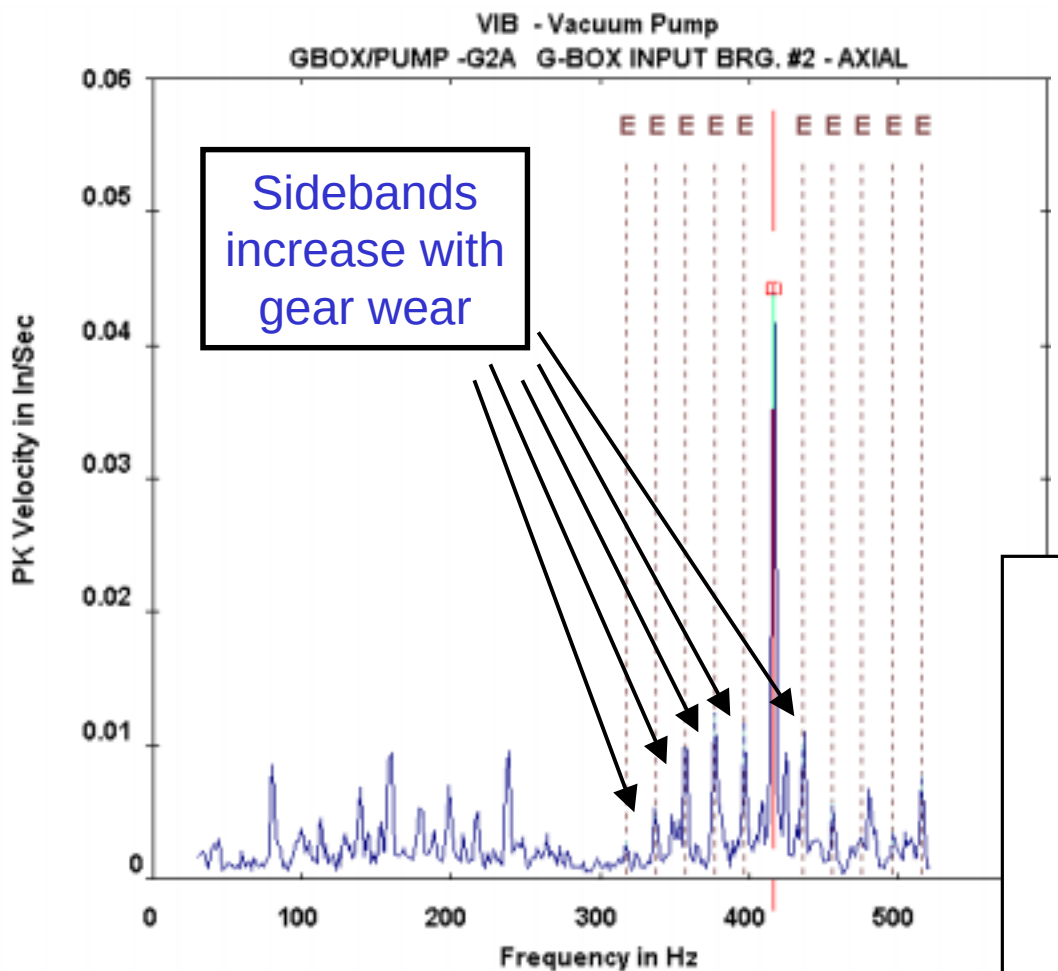


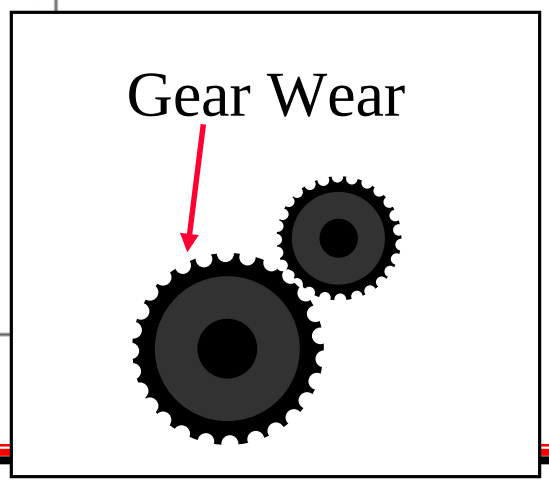
Looseness


FBRG - TENTER ZONE 3 SUPPLY FAN
8501-10#3S-F1A FAN BRG. #1 - AXIAL
PK VELOCITY IN IN/SEC
0.20
0.16
0.12
0.08
0.04
0
0
10
20
30
40
50
60
Frequency in Order
Looseness shows up as multiples of turning speed

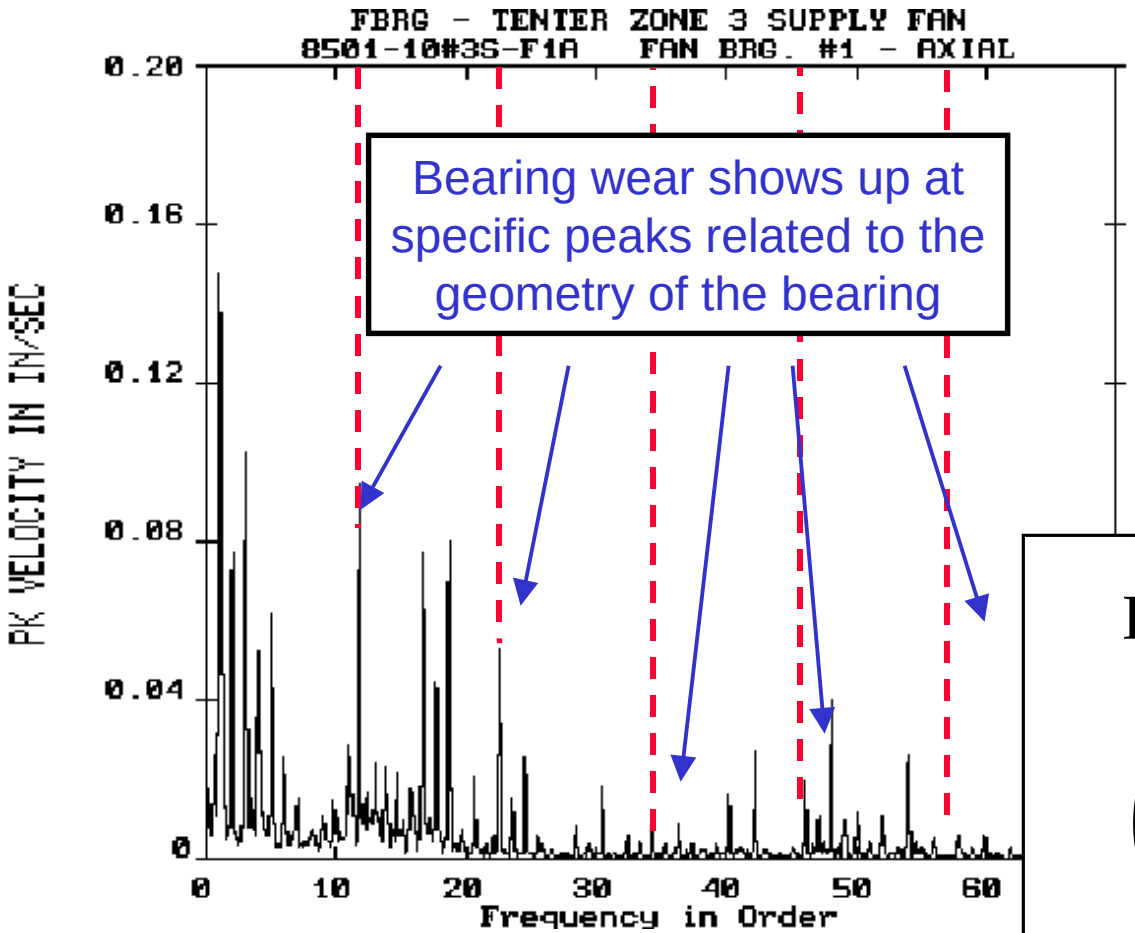

Looseness

Gear Mesh Fault

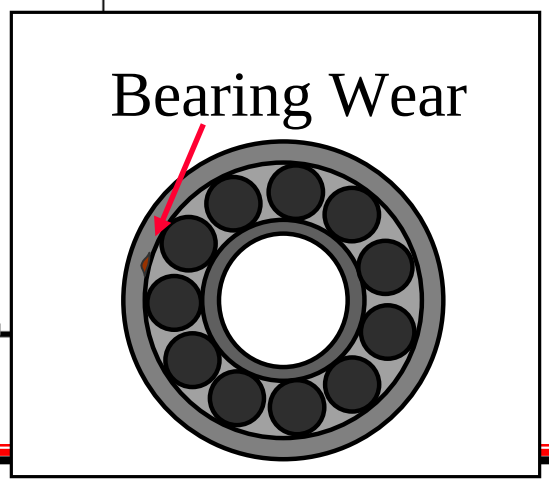




A Typical FFT Spectrum

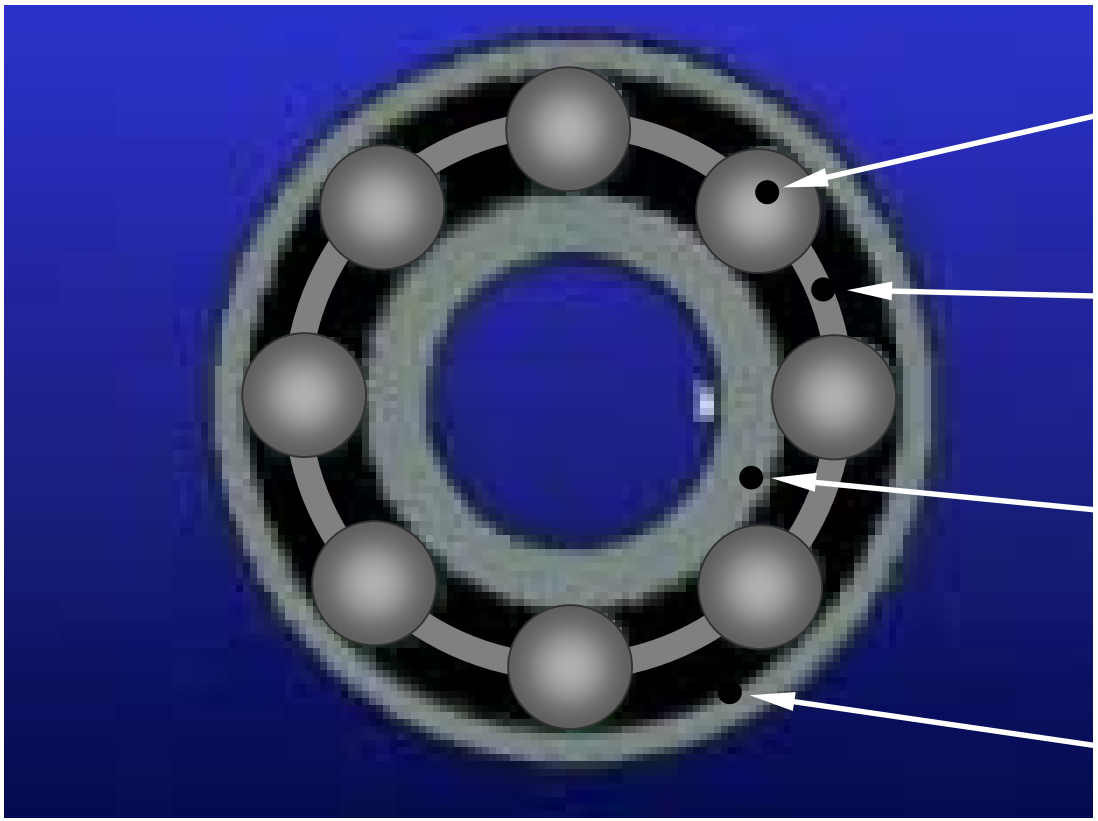


Bearing wear shows up at specific peaks related to the geometry of the bearing



Roller Bearing Faults

Four different bearing frequencies



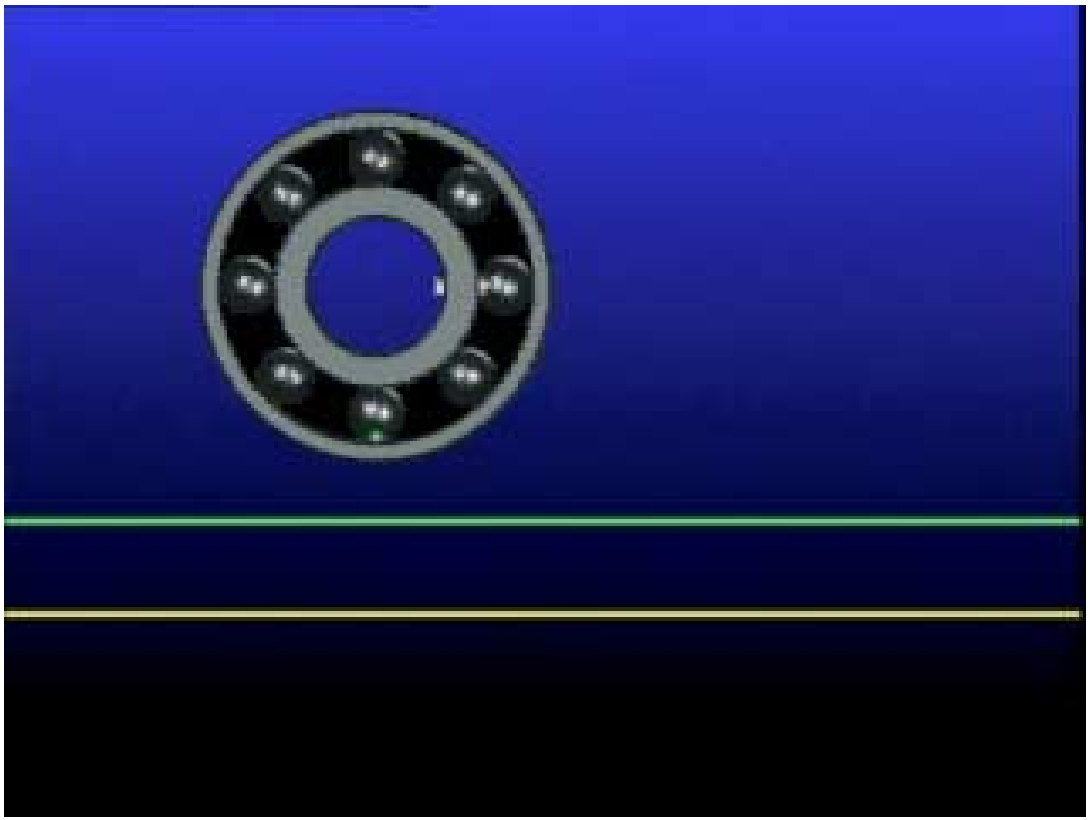
Ball Spin Frequency
(BSF)

Fundamental Train
Frequency
(FTF)

Ball Pass Frequency
Inner Race
(BPFI)

Ball Pass Frequency
Outer Race
(BPFO)

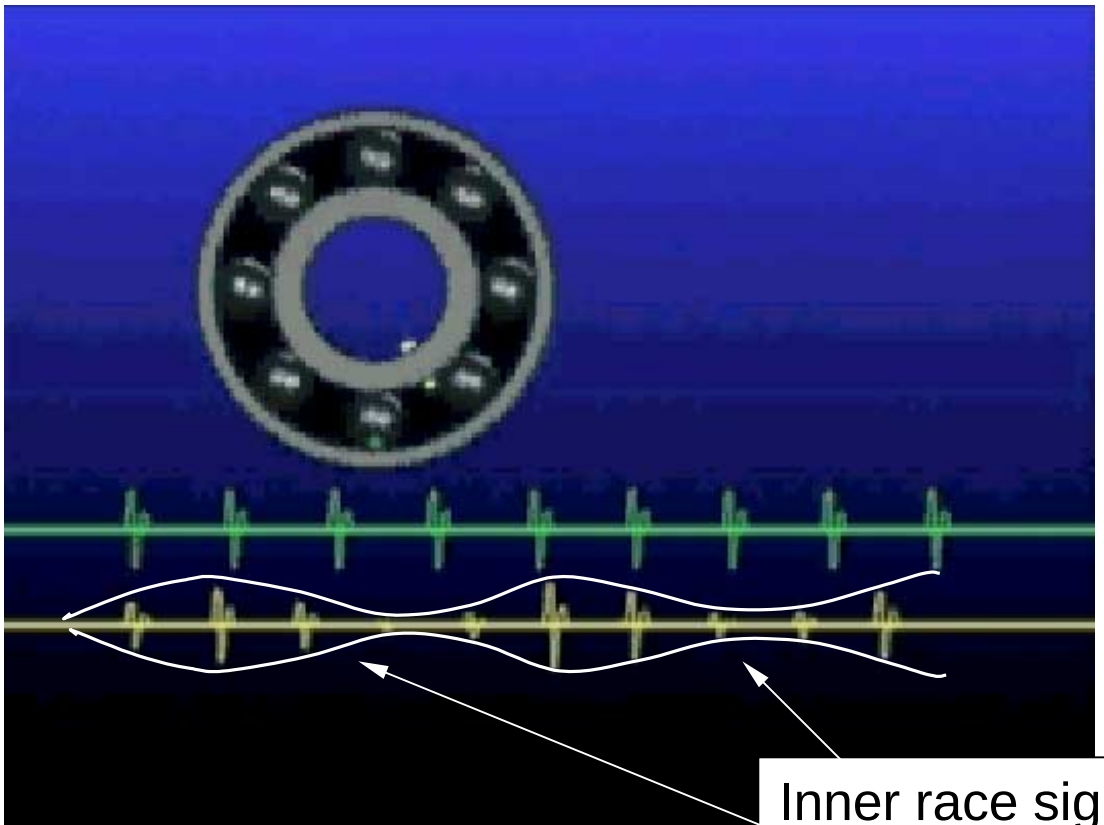
How Bearing Faults Generate Vibration



Outer Race Impacting

Inner Race Impacting

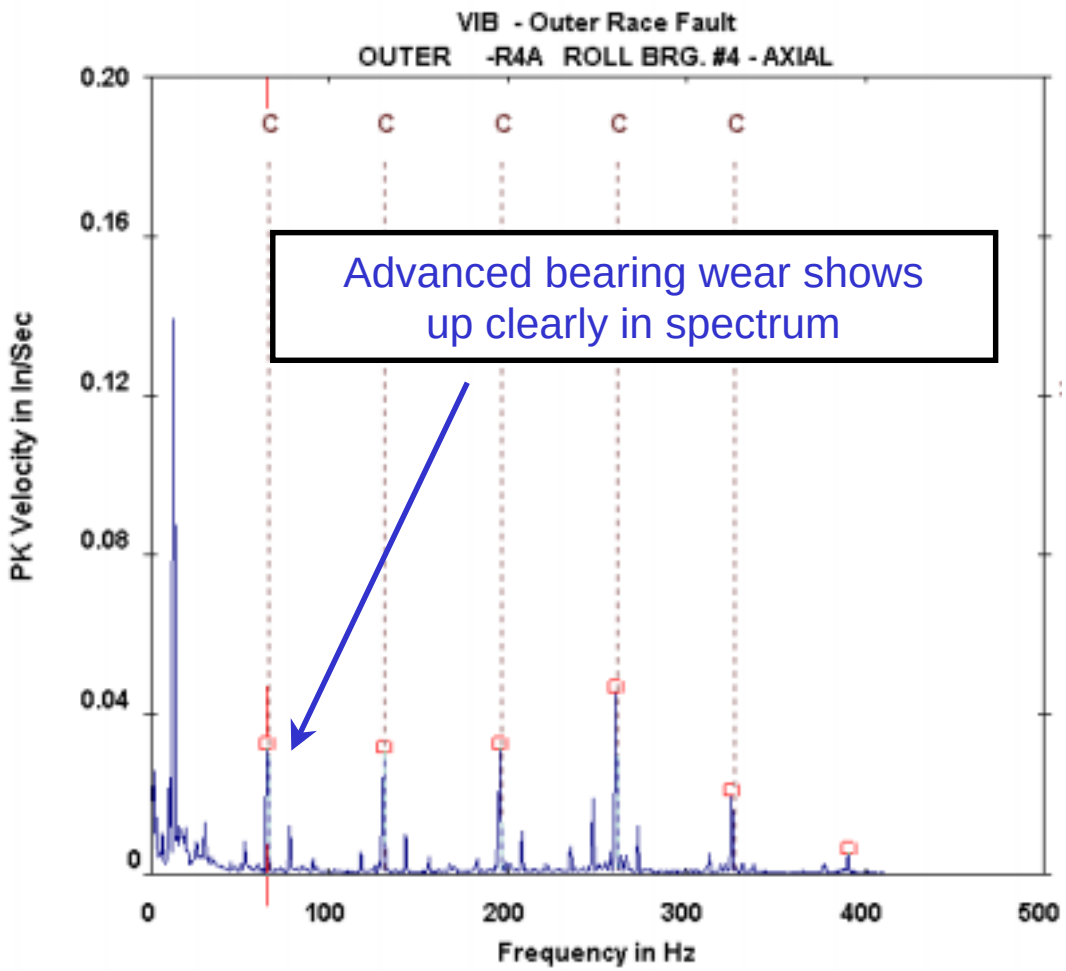
How Bearing Faults Generate Vibration



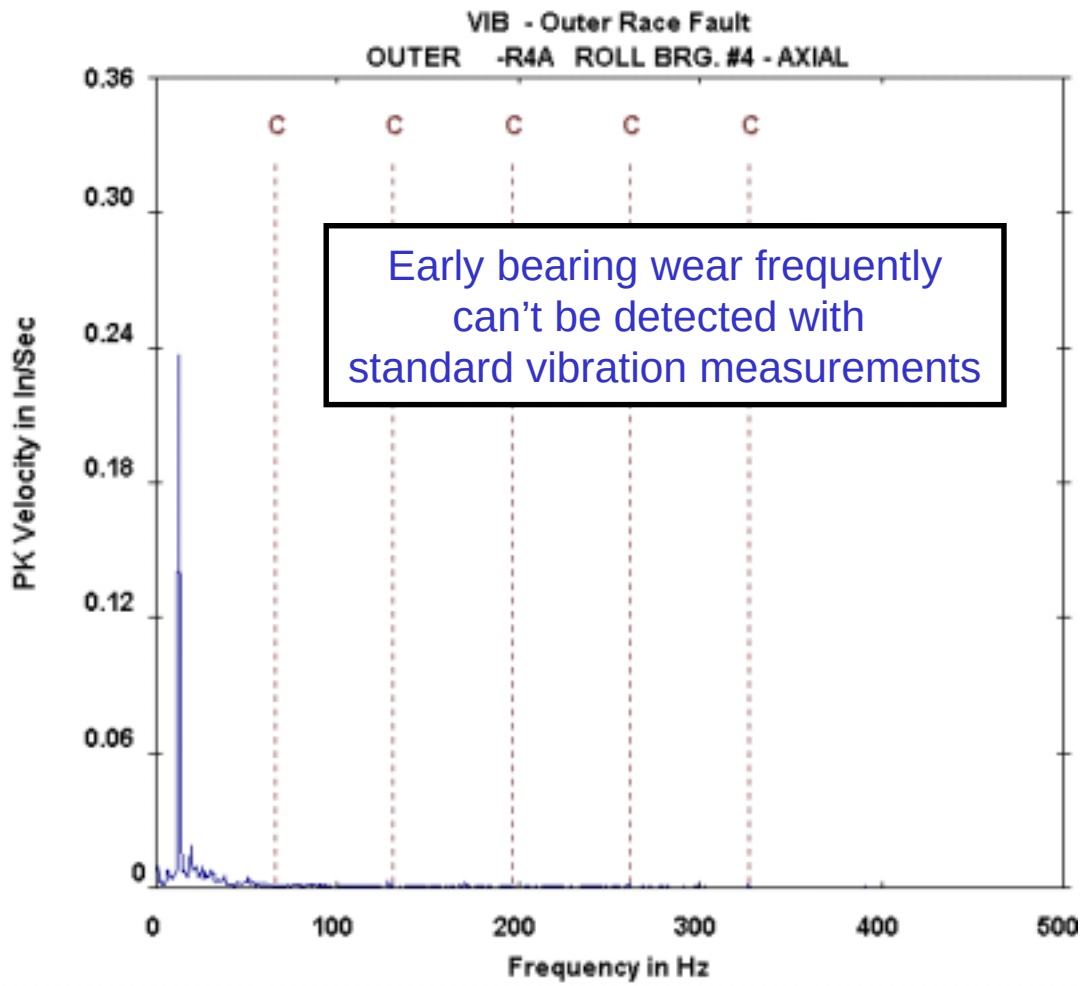
Outer Race Impacting

Inner Race Impacting

Actual Outer Race Defect



Onset of Outer Race Defect

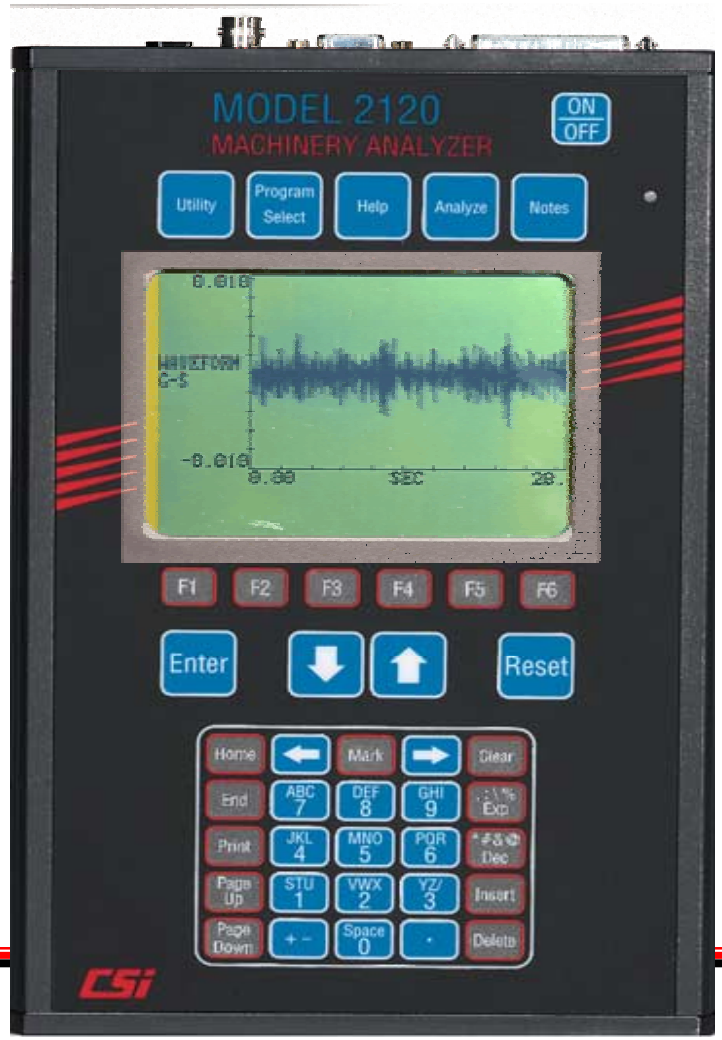


Early bearing wear frequently can't be detected with standard vibration measurements

Standard Waveform of Bad Bearing

Standard Waveform

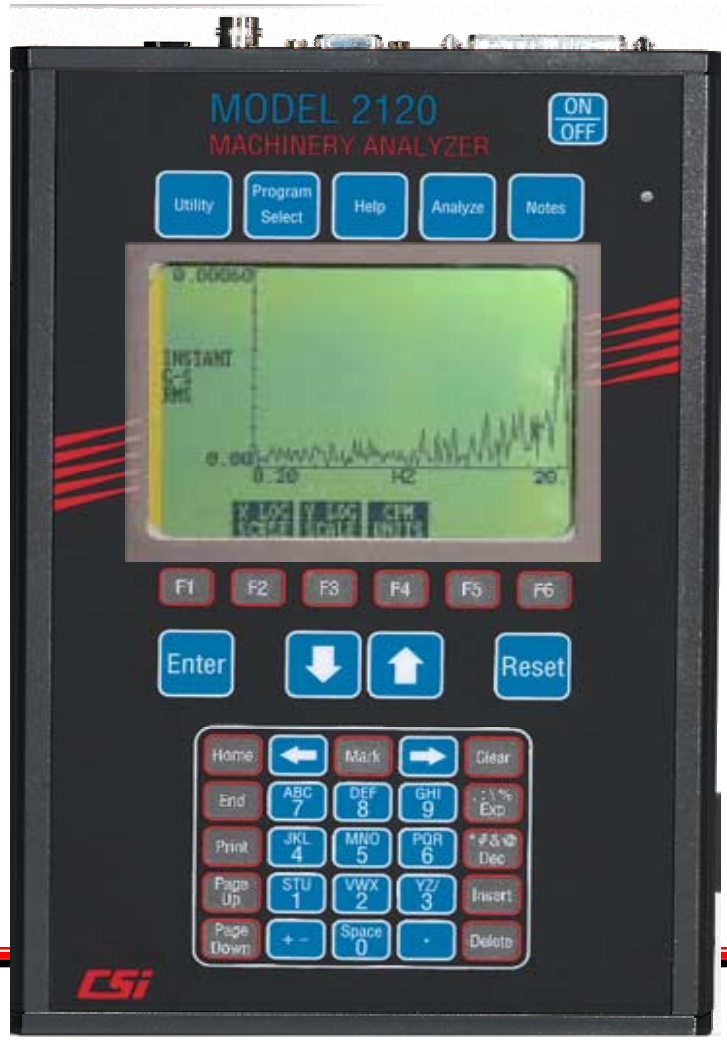
- some level of impacting visible



Standard FFT of Bad Bearing

Standard FFT

•high frequency signals
•no clear indication



PeakVue Waveform of Bad Bearing

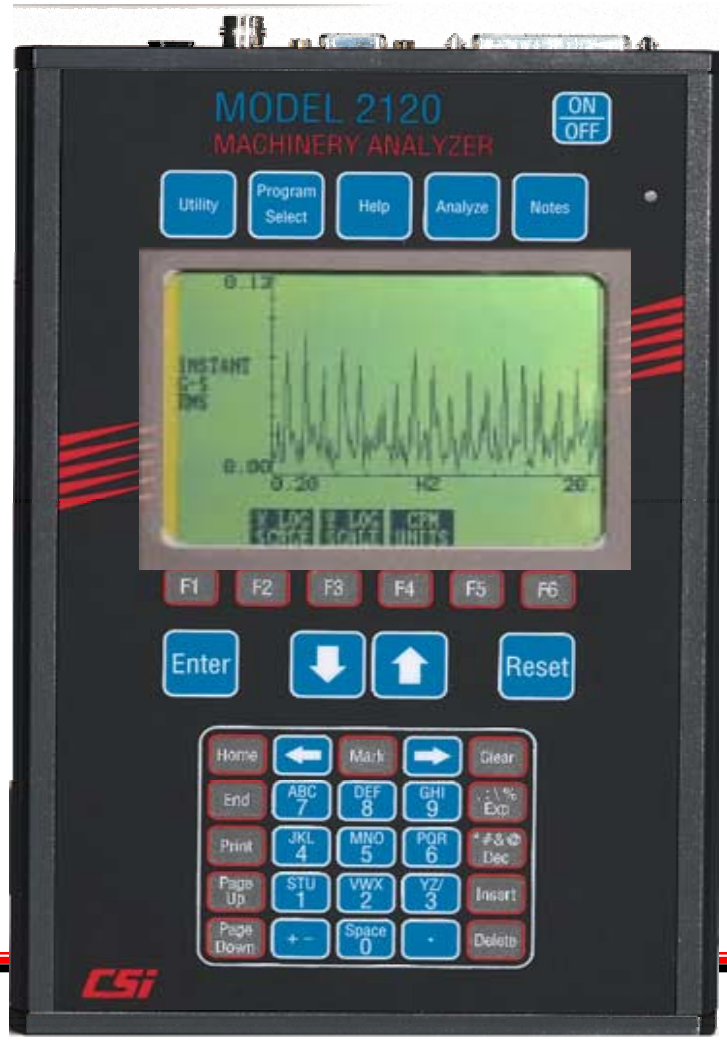
PeakVue Waveform

- focuses on bearing impacting
- clear indication of bearing wear

PeakVue FFT of Bad Bearing

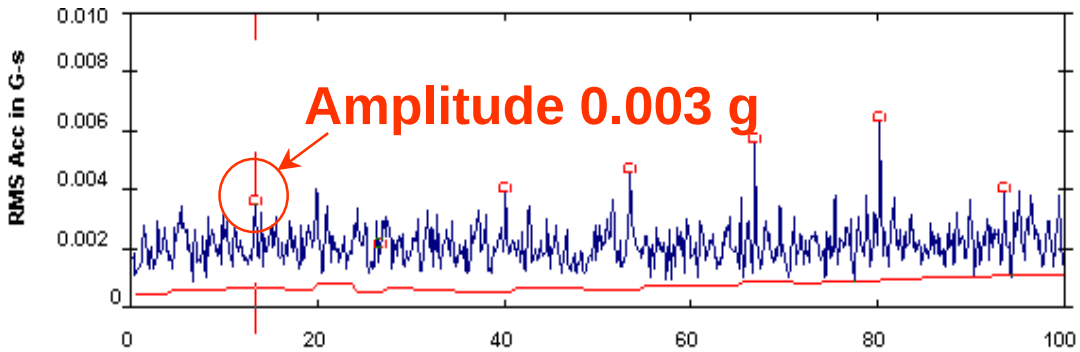
PeakVue Spectrum

- high frequency signals brought to low frequency
- clear indication of bearing fault



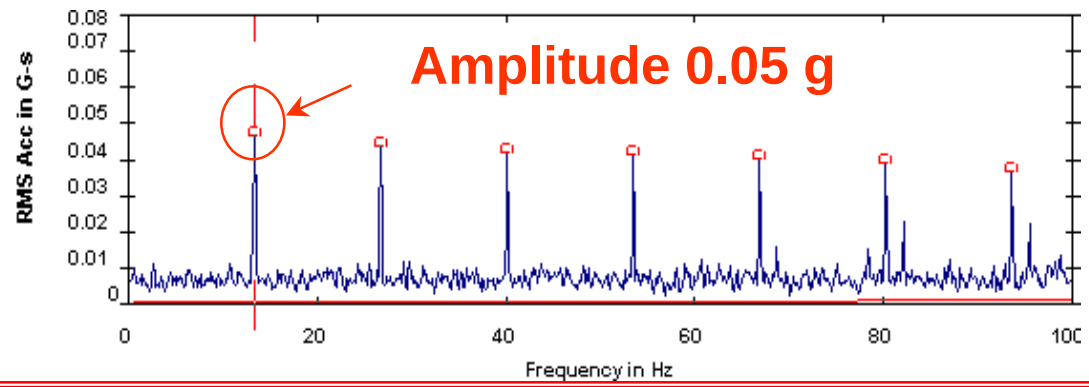
Demodulation vs. PeakVue

Demodulation



Demodulation and PeakVue each detect early bearing wear

PeakVue



PeakVue shows:

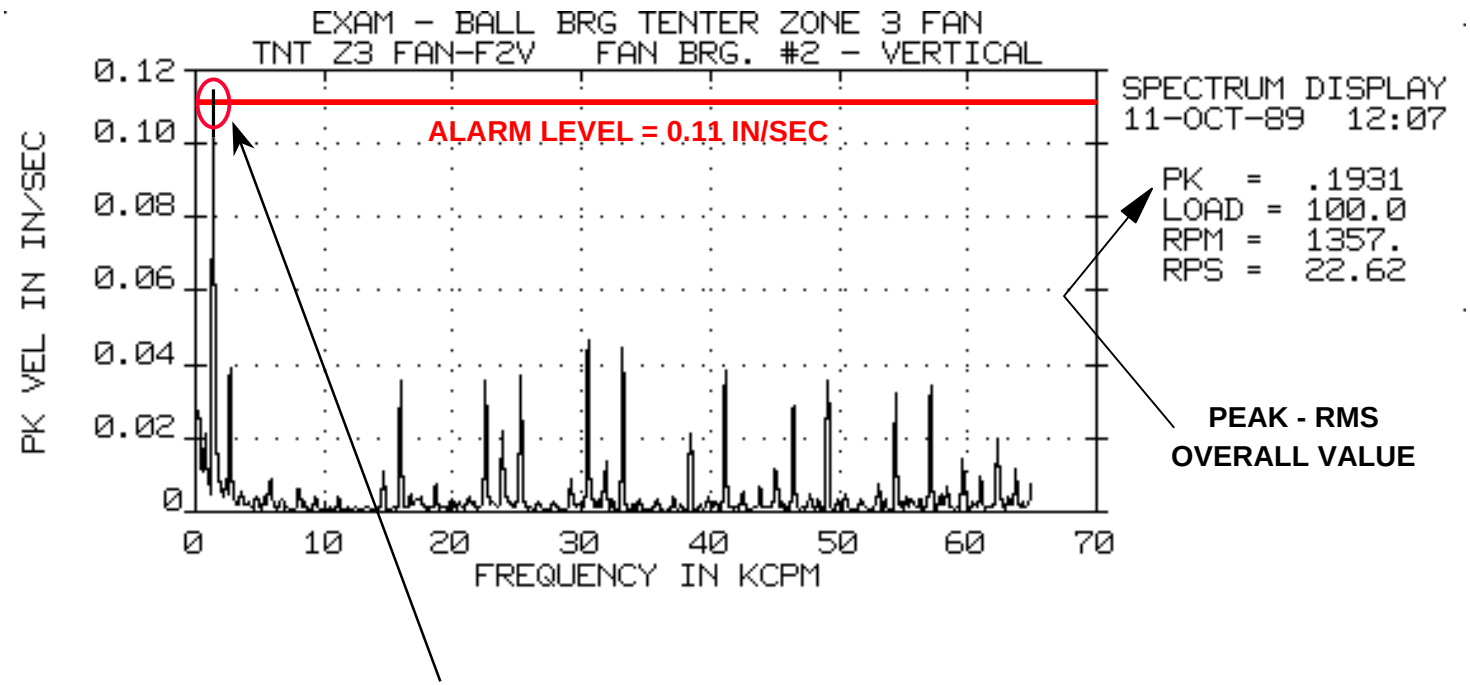
- fault more clearly
- less signal noise
- actual amplitude

Detecting Faults Automatically

Vibration Alarming Methods

Overall Alarm

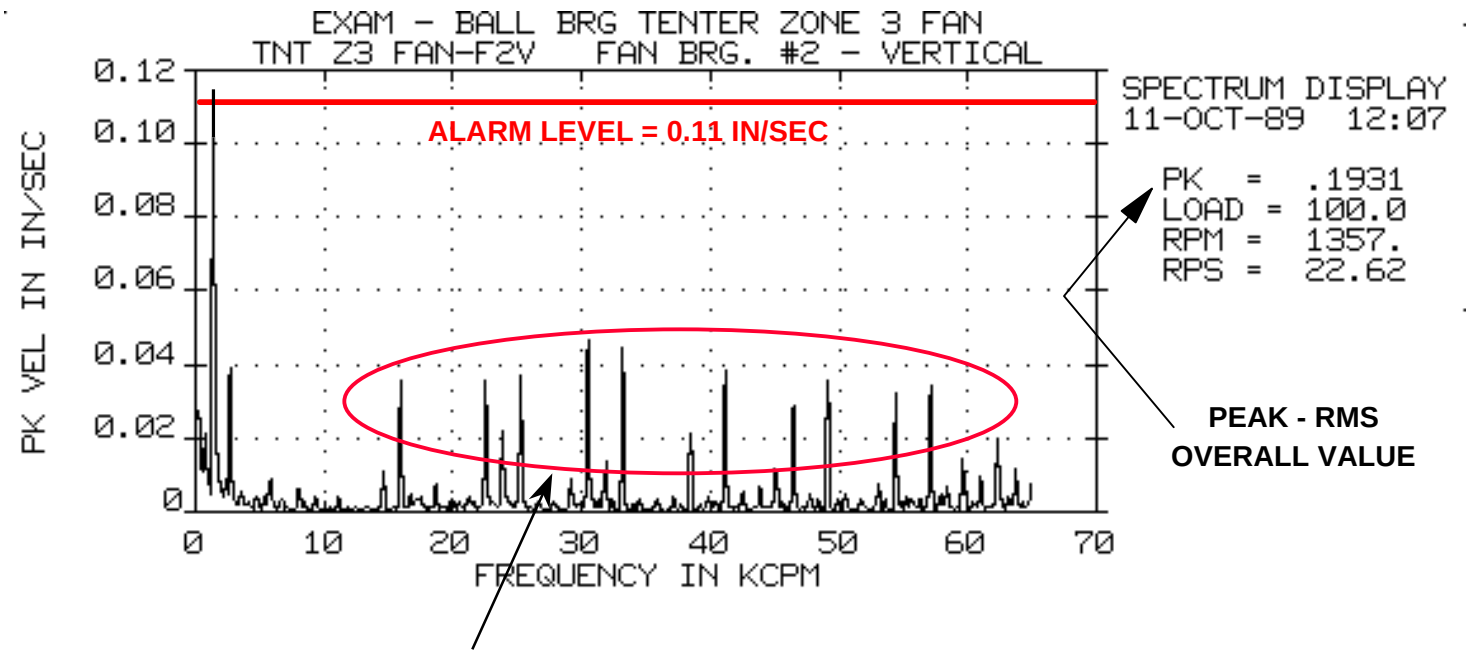
Total vibration on machine



May detect imbalance vibration (typically higher amplitudes)

Overall Alarm

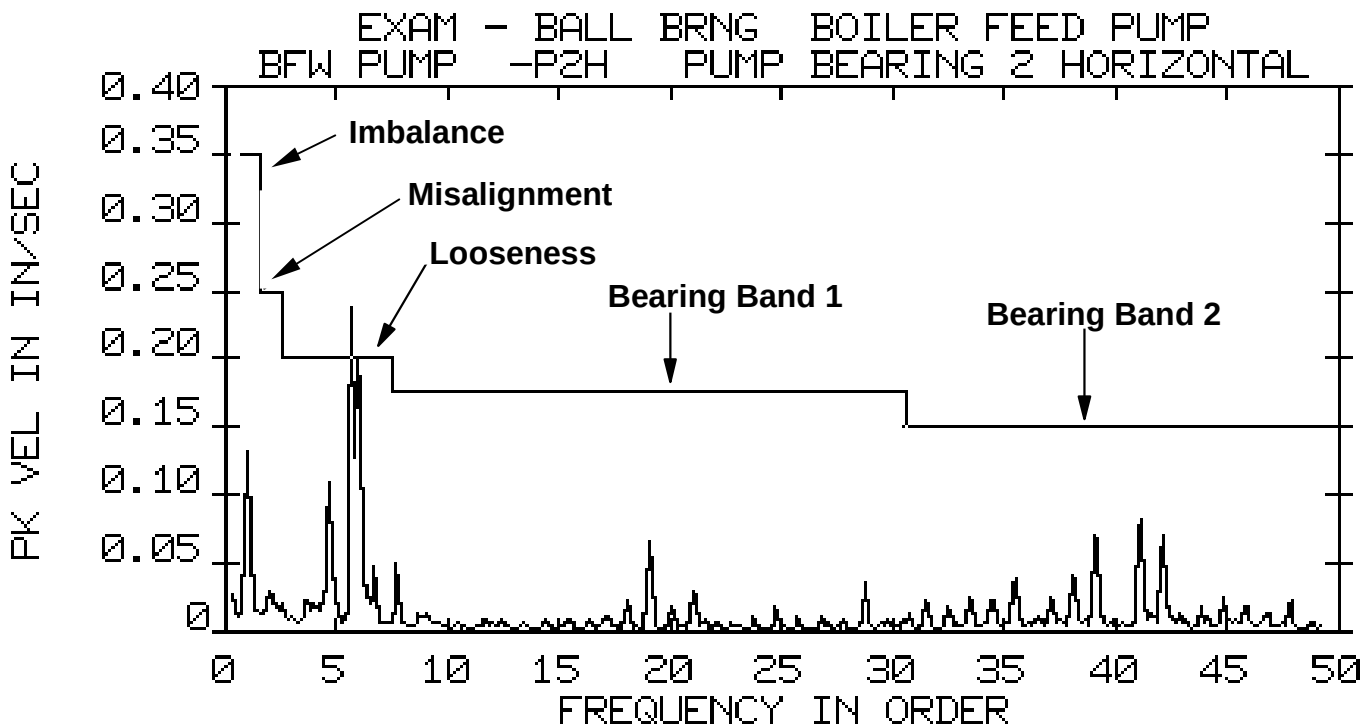
Total vibration on machine



Not sensitive enough for even advanced bearing faults (typically low amplitude signals)

Frequency Bands

Divide spectrum in frequency bands based on the
types of mechanical faults that might appear on the machine



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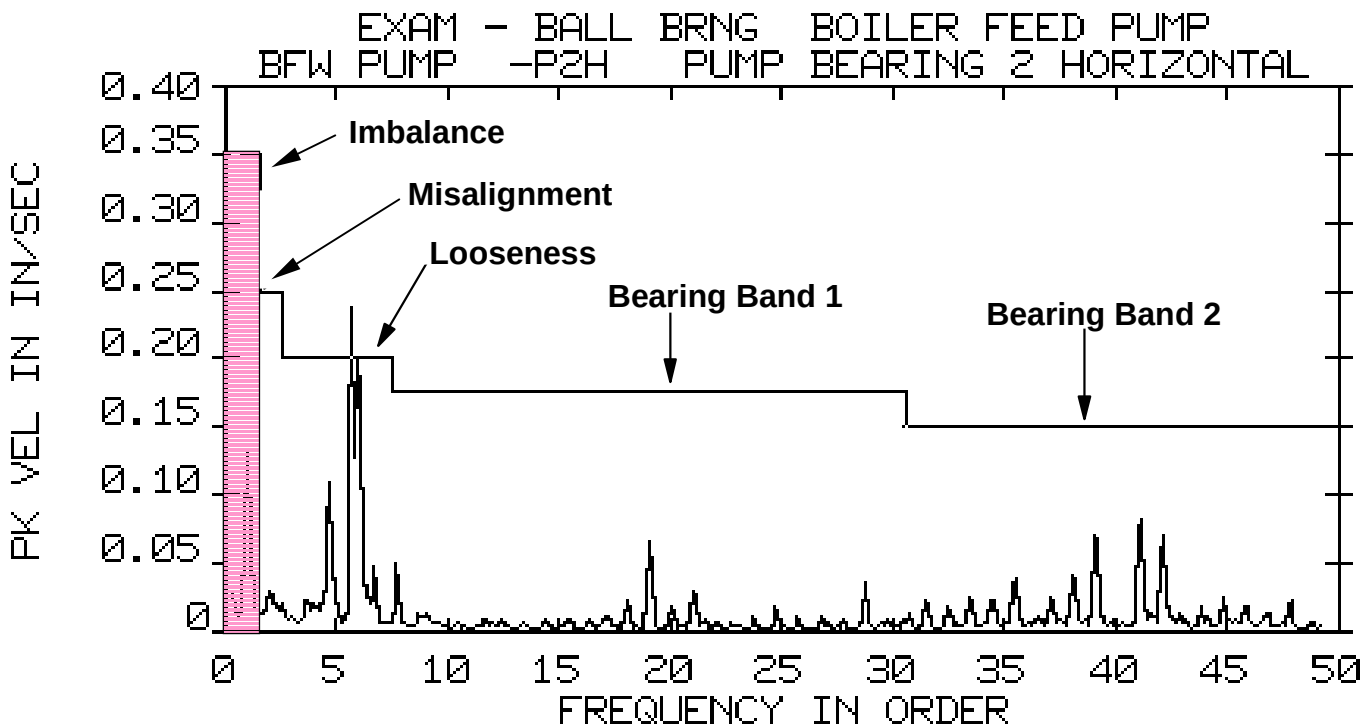
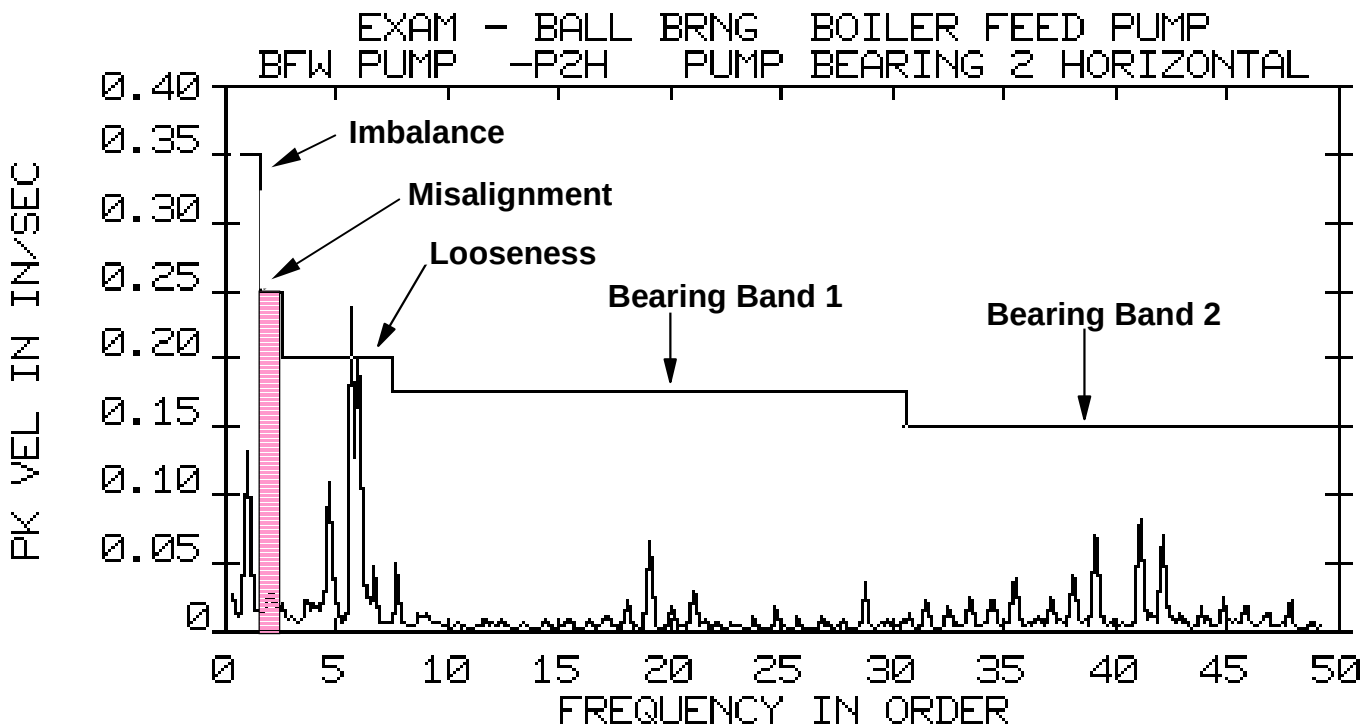
types of mechanical faults that might appear on the machine



Frequency Bands

Divide spectrum in frequency bands based on the
types of mechanical faults that might appear on the machine



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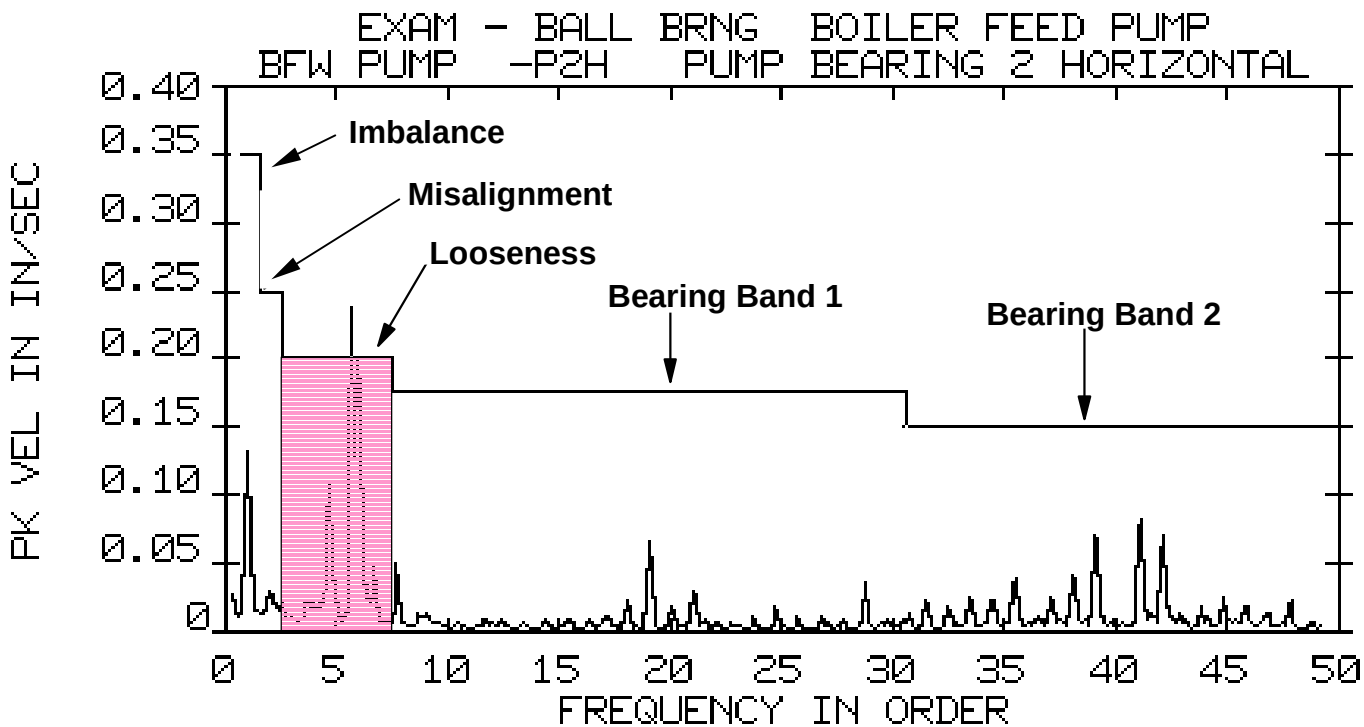

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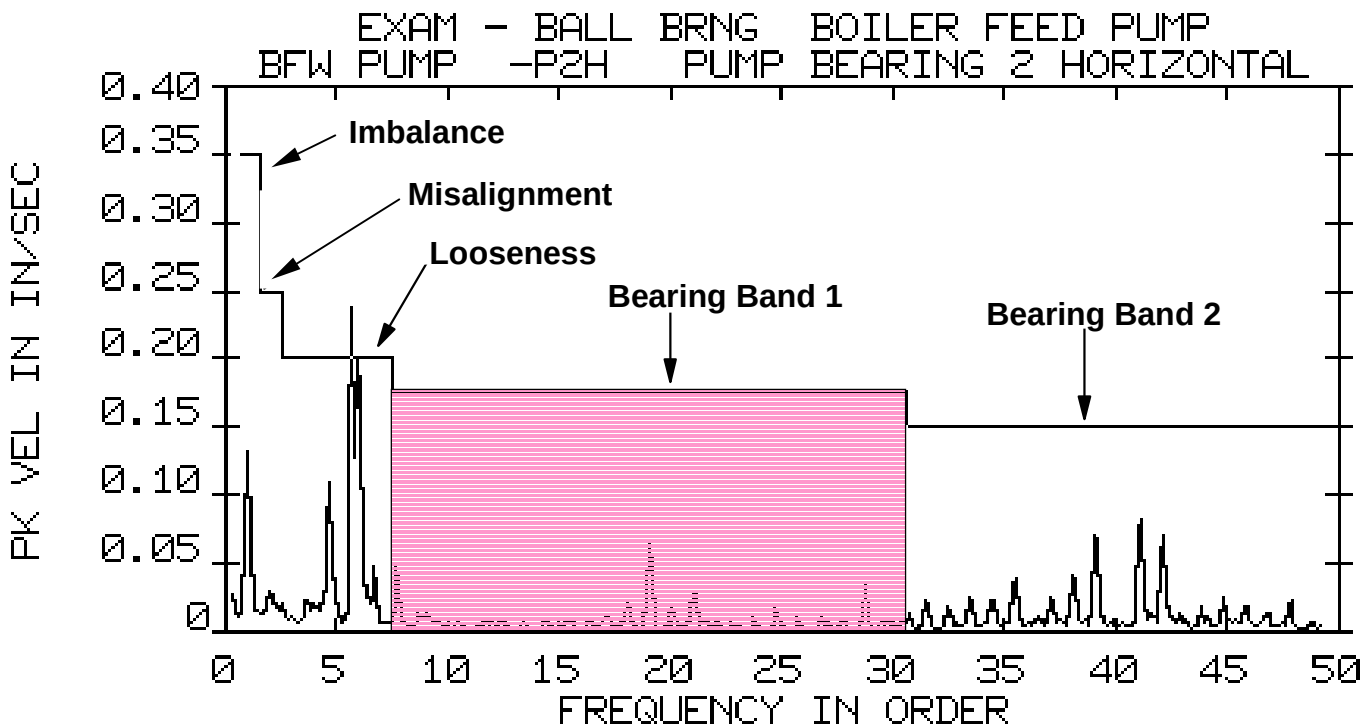

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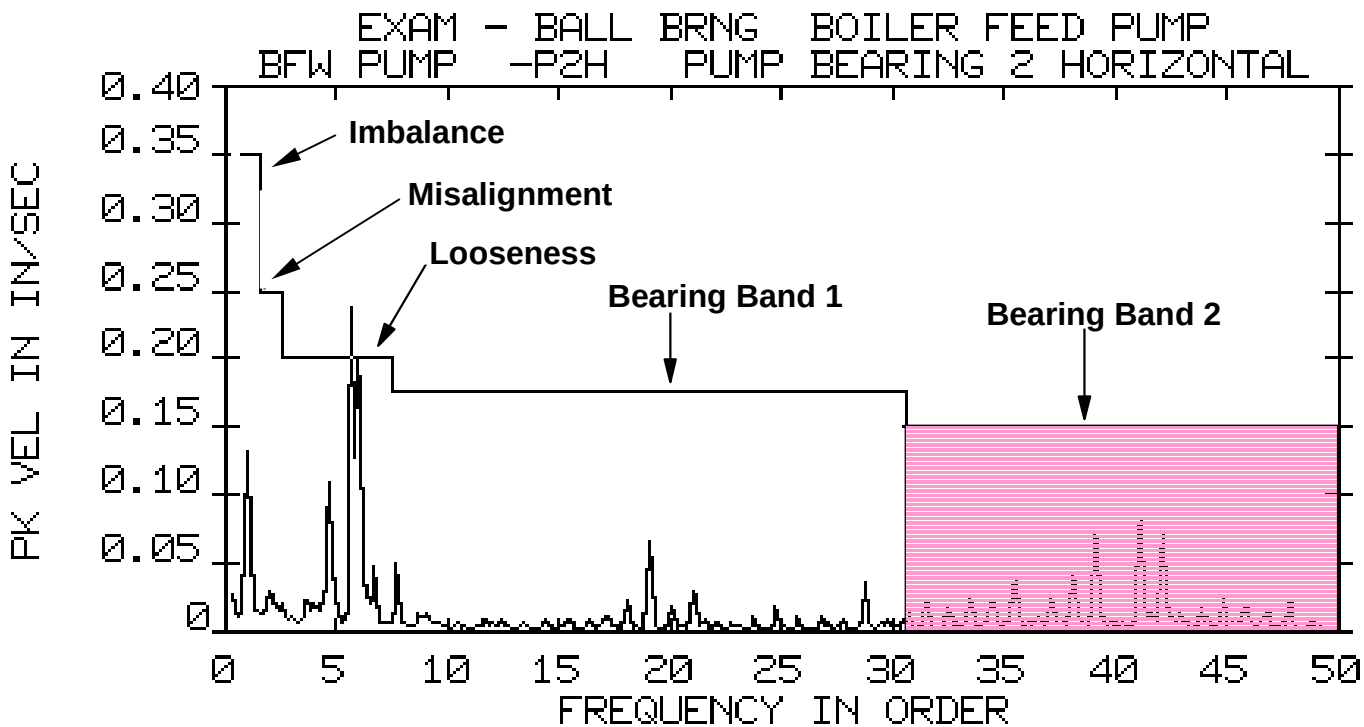
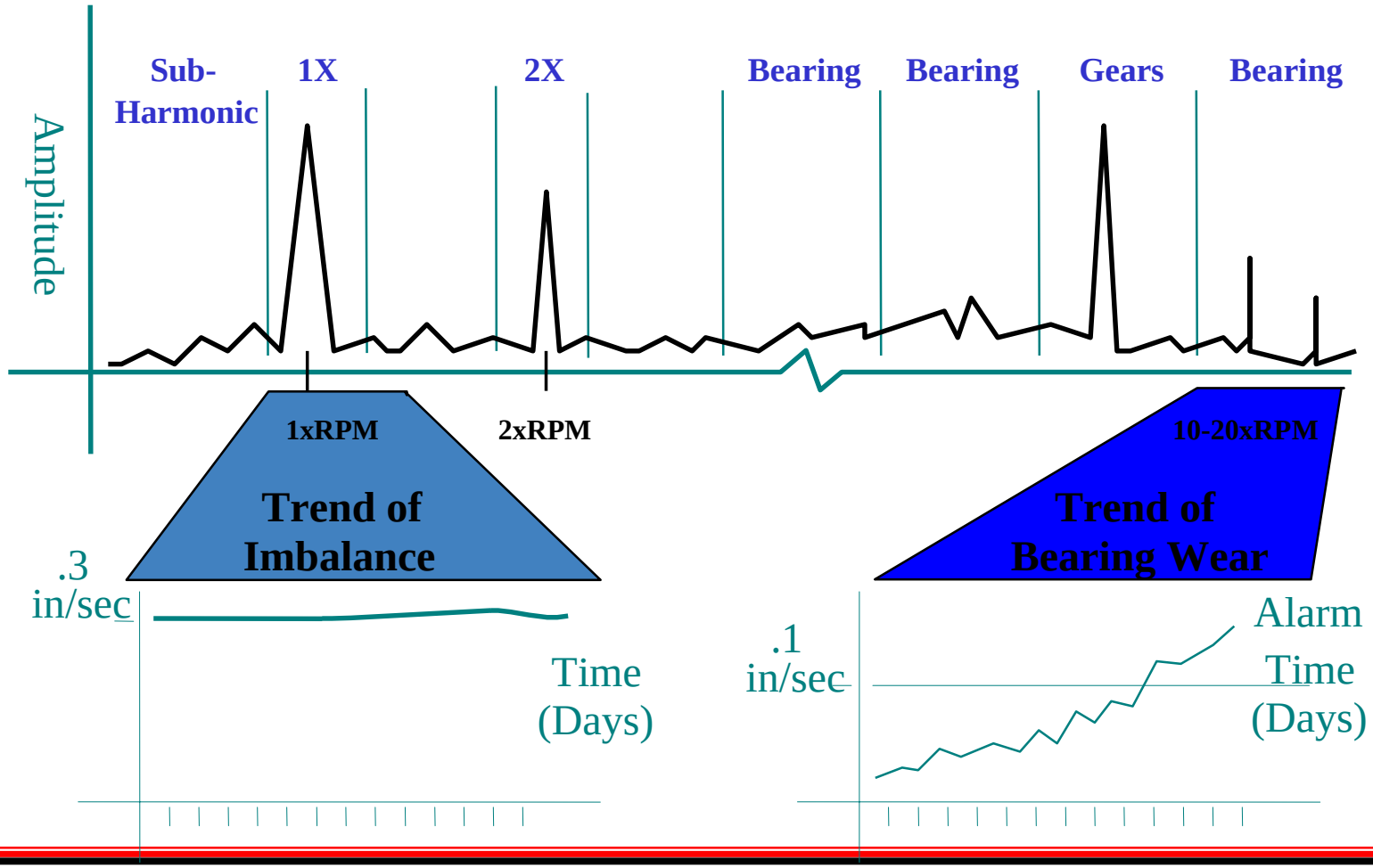


Frequency Bands with Trend



Establishing a Vibration Program

- Define program focus

TECHNICAL STEPS

- Determine collection method(s)
- Create database
- Collect data
- Detect developing faults
- Diagnose nature and extent of fault

- Document business and maintenance implications

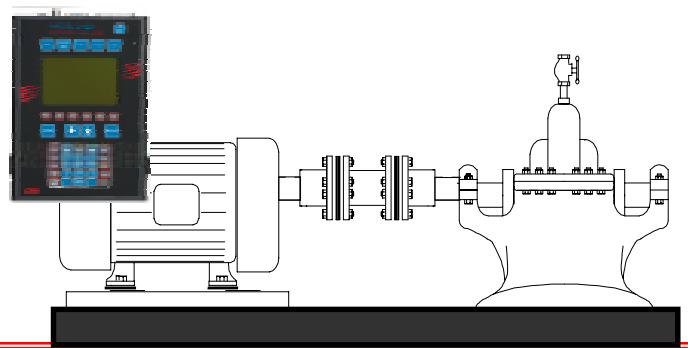
BUSINESS STEPS

Step 1: Define program focus

- Identify Critical Machines
  - Effect on production
  - Availability of back-up machine
  - Cost to repair
  - Time to repair

Step 2: Determine Collection Method(s)

- Route-based periodic
  - general plant equipment
  - walk around survey
  - manual measurement
  - monthly reading typical
  - readily accessible



- [redacted]

Single vs. Dual Channel Analysis

	Single Channel Analysis	Dual Channel Analysis
Implementation	Lower cost, reduced training	Higher cost, Increased training
Focus	Detect developing machine faults	Analyze machine structure
Purpose	Identify component wear (fault type)	Indentify wear mechanism (root cause)
Application	General application across most equipment	Typically only for problem machines

On-line vs. Off-line Monitoring

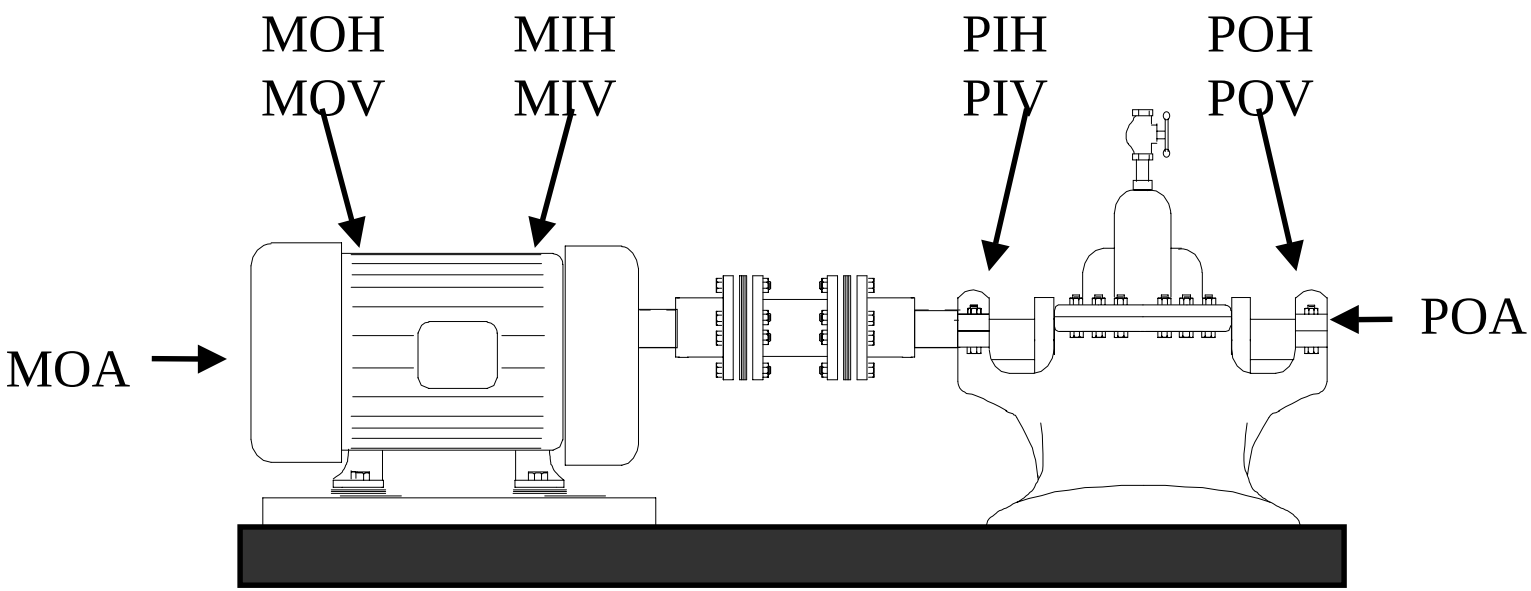
	Periodic measurement (route-based survey)	Continuous (on-line monitoring)
Implementation	Lower capital cost, increased labor cost	Higher capital cost, minimal labor cost
Focus	Monthly measurement (Detect prior to failure)	Continuous update (Detect at on-set)
Purpose	Maximize plant availability	Protect assets, ensure safety & availability
Application	General application across most equipment	Most applicable to critical plant equipment

Step 3: Create database

- Enter machines information
  - Machine ID (asset code)
  - Description
  - Operating speed (RPM)

- Define measurement points
  - Point ID (identification)
  - Description
  - Sensor type (accelerometer)
  - Analysis Parameters (how to analyze signal)
  - Alarm Limits (allowable amount of vibration)

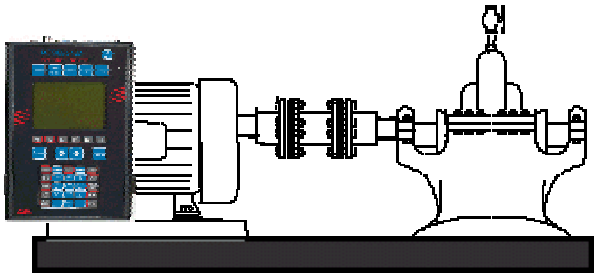
Measurement Point Locations



2 per bearing + 1 axial measurement per shaft

Automated Database Set-up

Step 4: Collect Data

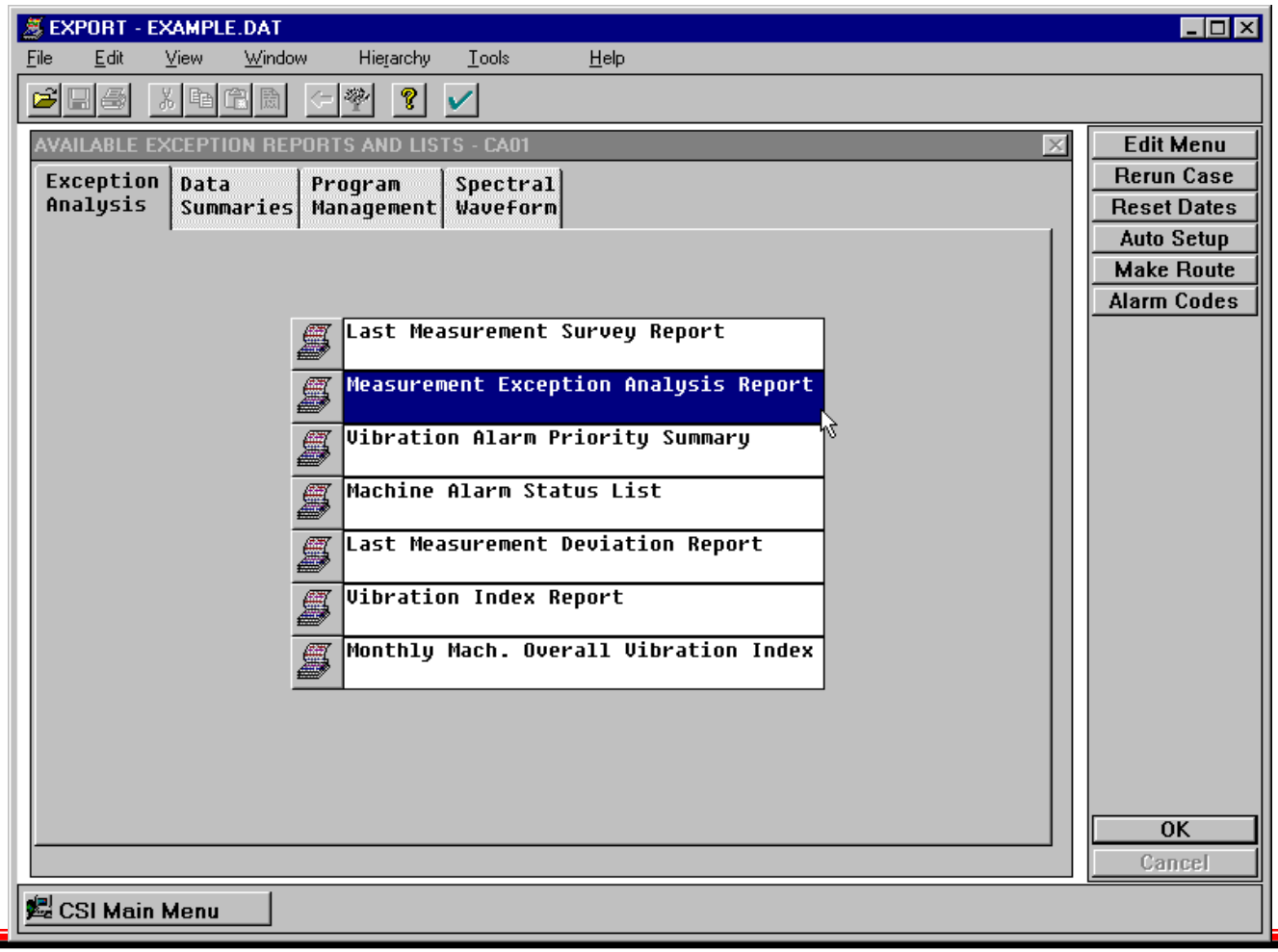


1) Periodic walk-around survey

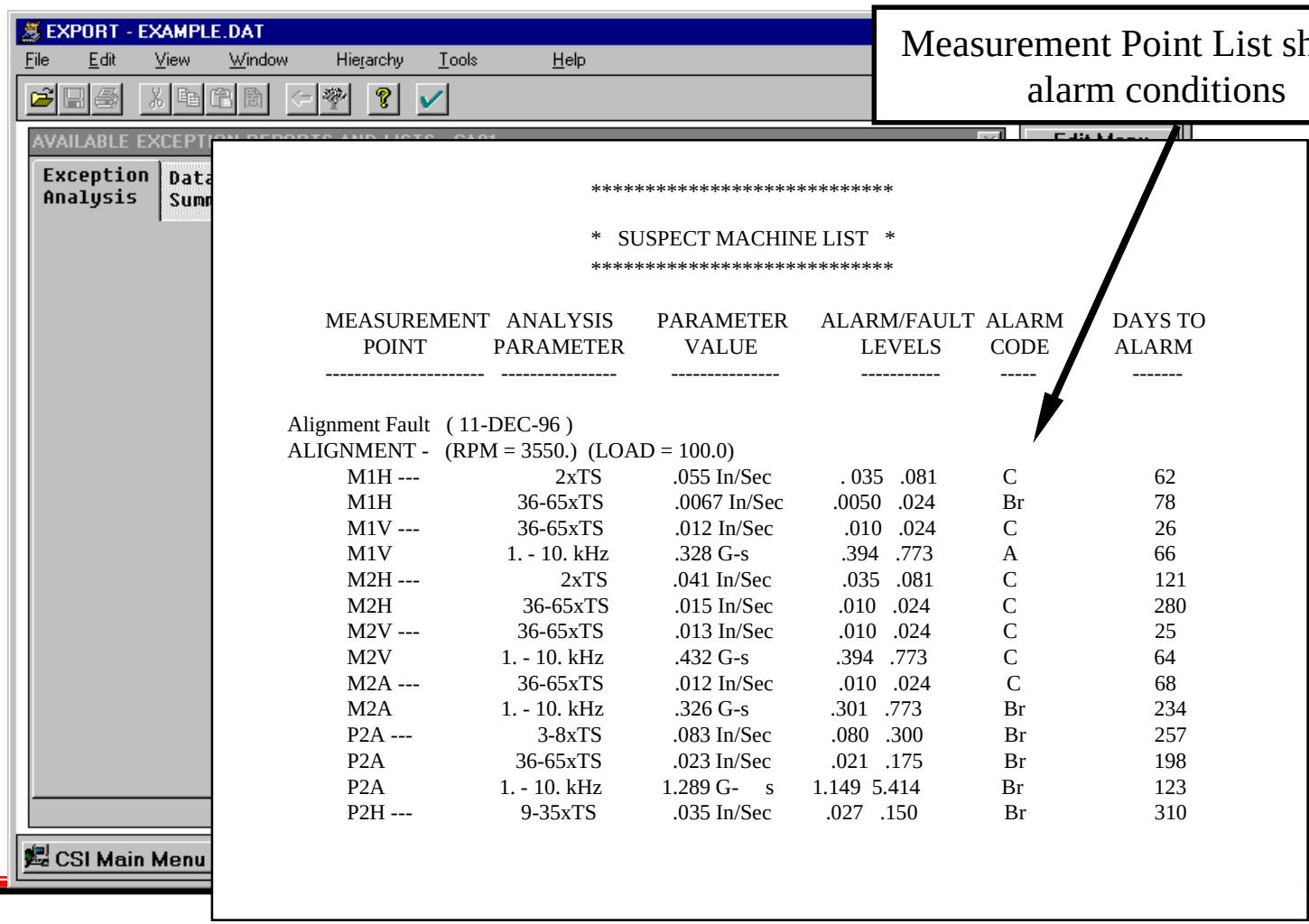
2) Smart sensor with periodic data transfer

3) Continuous and on-line

Step 5: Detect Developing Faults



Step 5: Detect Developing Faults



Measurement Point List showing alarm conditions

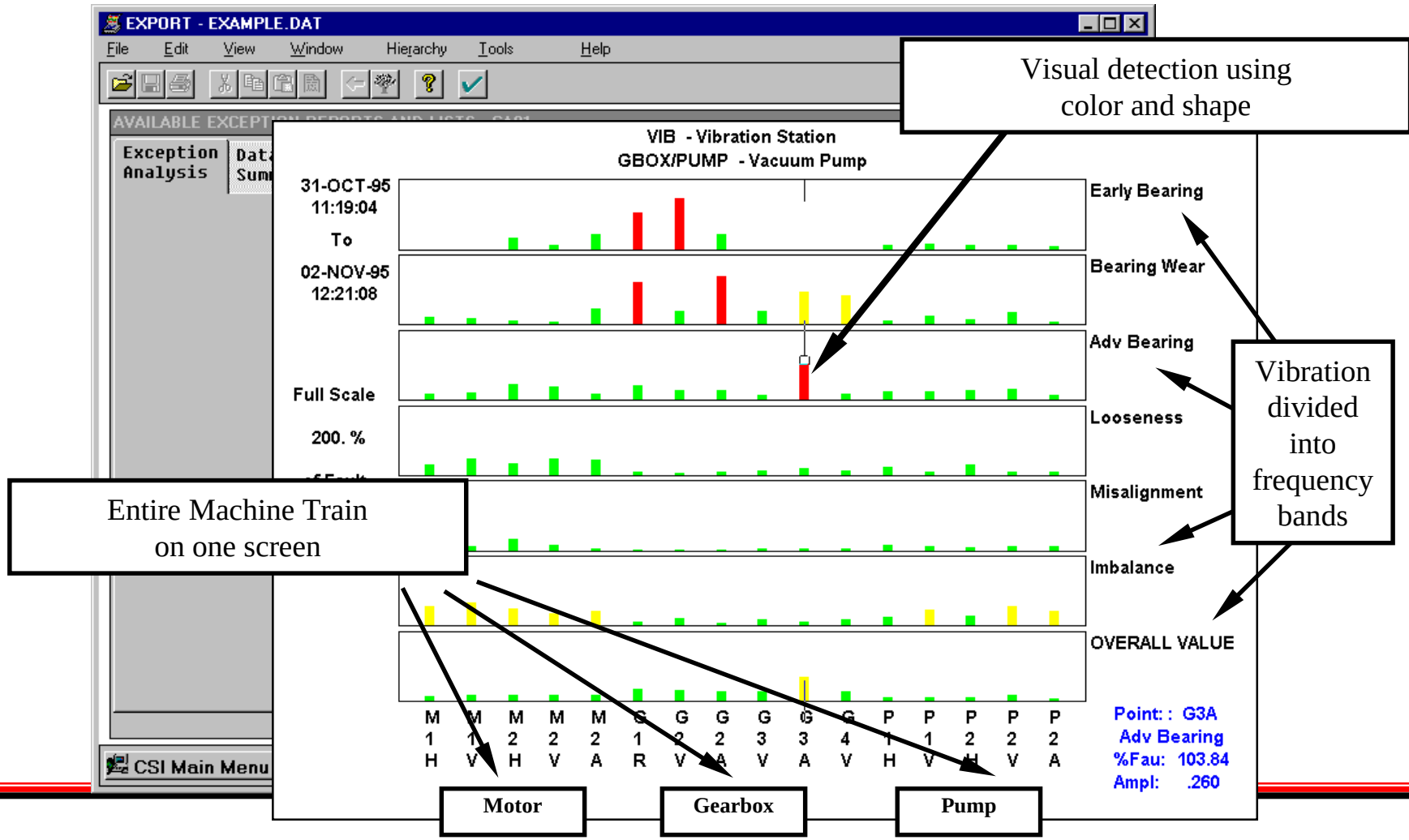
****

* SUSPECT MACHINE LIST *

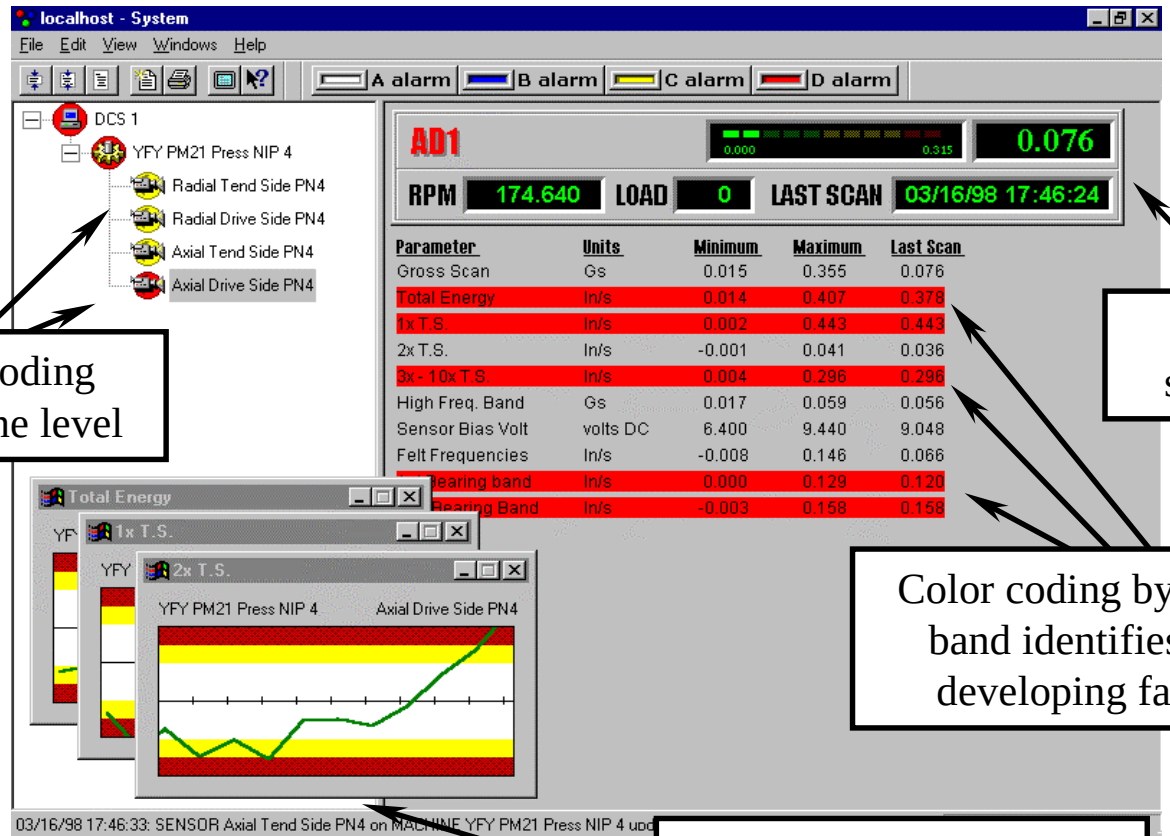
****

MEASUREMENT POINT	ANALYSIS PARAMETER	PARAMETER VALUE	ALARM/FAULT LEVELS	ALARM CODE	DAYS TO ALARM
Alignment Fault (11-DEC-96)					
ALIGNMENT - (RPM = 3550.) (LOAD = 100.0)					
M1H ---	2xTS	.055 In/Sec	. 035 .081	C	62
M1H	36-65xTS	.0067 In/Sec	.0050 .024	Br	78
M1V ---	36-65xTS	.012 In/Sec	.010 .024	C	26
M1V	1. - 10. kHz	.328 G-s	.394 .773	A	66
M2H ---	2xTS	.041 In/Sec	.035 .081	C	121
M2H	36-65xTS	.015 In/Sec	.010 .024	C	280
M2V ---	36-65xTS	.013 In/Sec	.010 .024	C	25
M2V	1. - 10. kHz	.432 G-s	.394 .773	C	64
M2A ---	36-65xTS	.012 In/Sec	.010 .024	C	68
M2A	1. - 10. kHz	.326 G-s	.301 .773	Br	234
P2A ---	3-8xTS	.083 In/Sec	.080 .300	Br	257
P2A	36-65xTS	.023 In/Sec	.021 .175	Br	198
P2A	1. - 10. kHz	1.289 G- s	1.149 5.414	Br	123
P2H ---	9-35xTS	.035 In/Sec	.027 .150	Br	310

Step 5: Detect Developing Faults



Step 5: Detect Faults On-line



Color coding at machine level

Point statistics

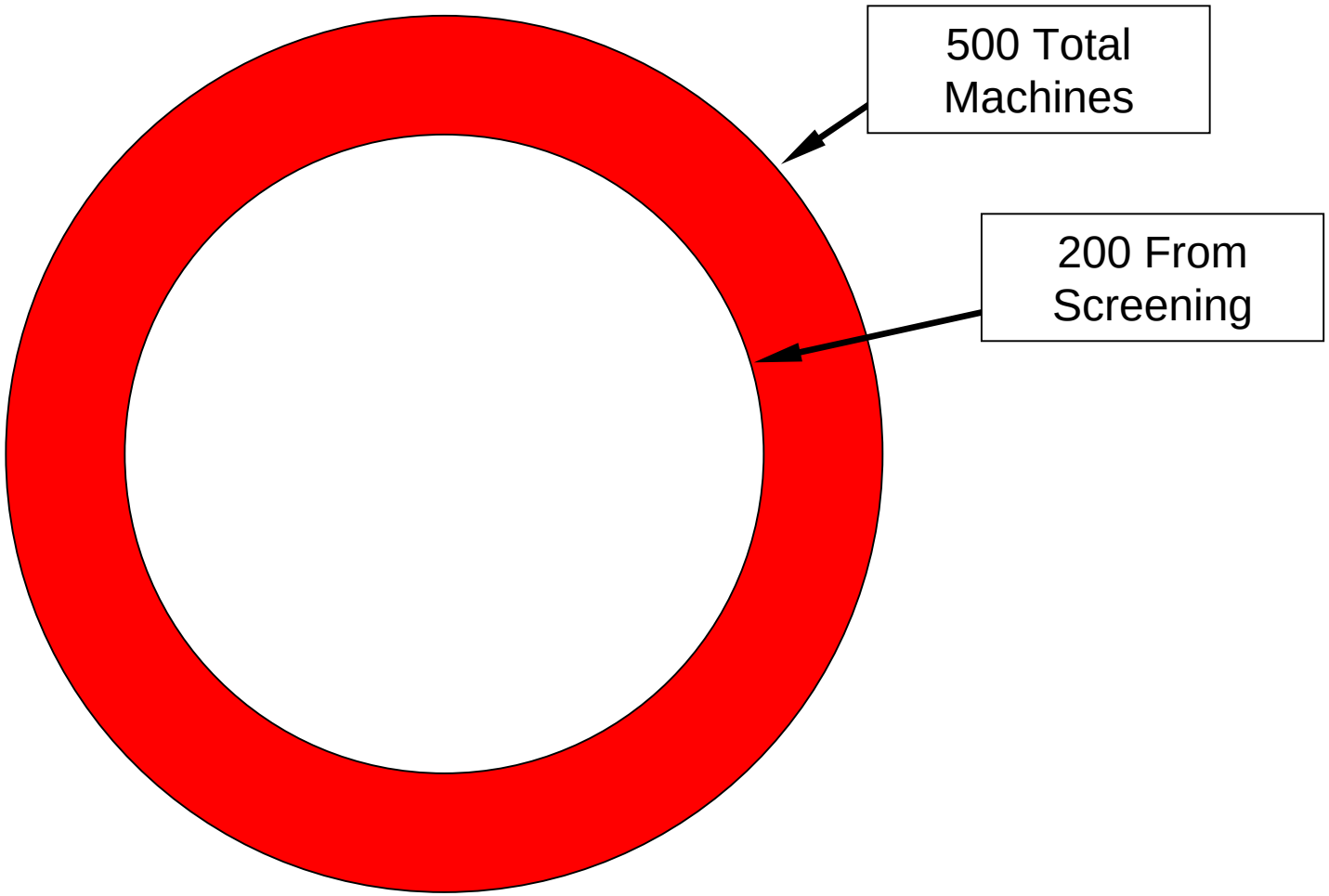
Color coding by frequency band identifies specific developing fault types

On-line trend indicates rate of change

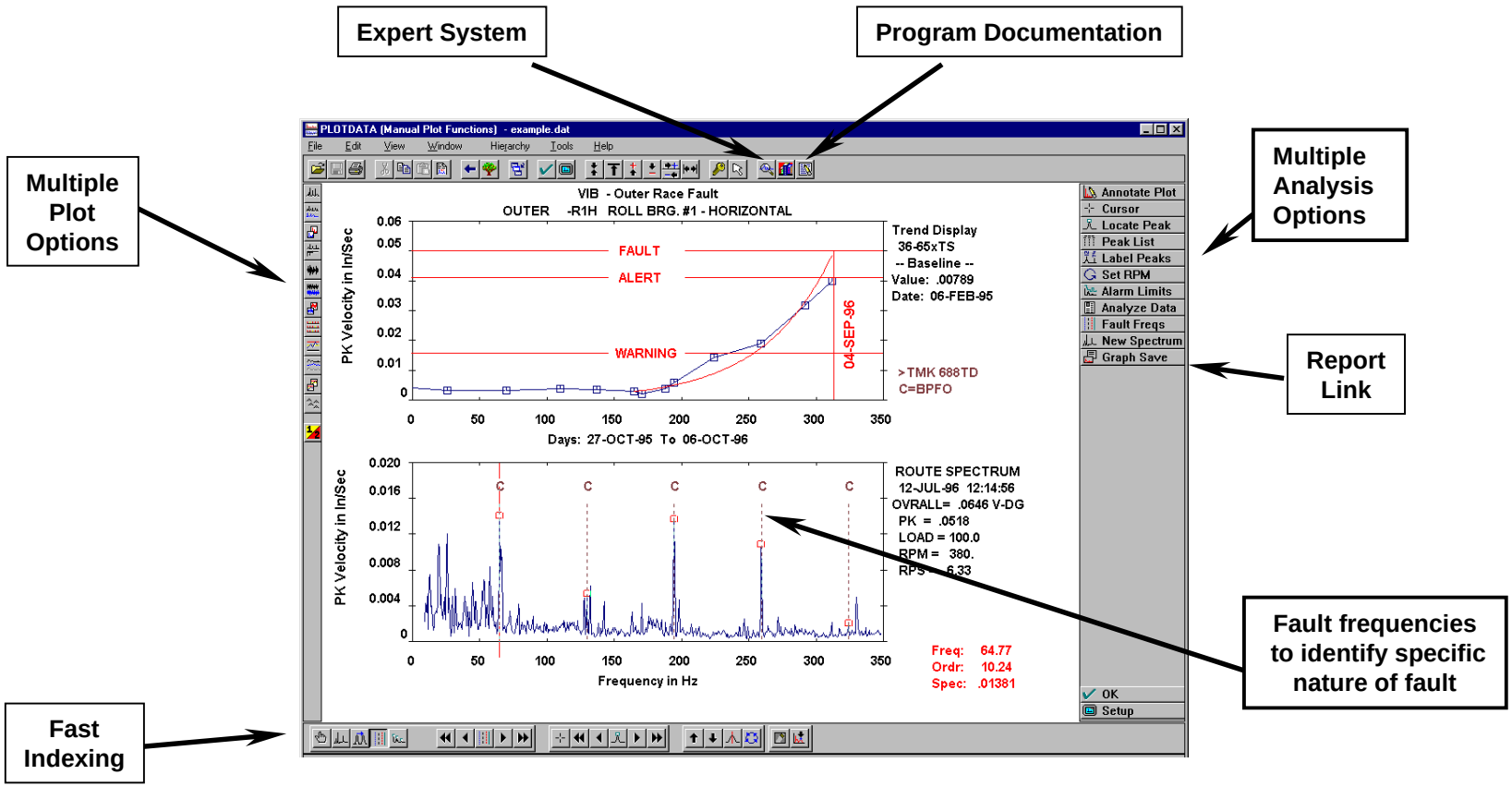
Advantages of On-line Approach

- Continuous monitoring of critical equipment
- Automatic scan for developing machine faults
- Immediate notification of alarm conditions
- Extensive data history available for diagnosis

Screening Vibration Data

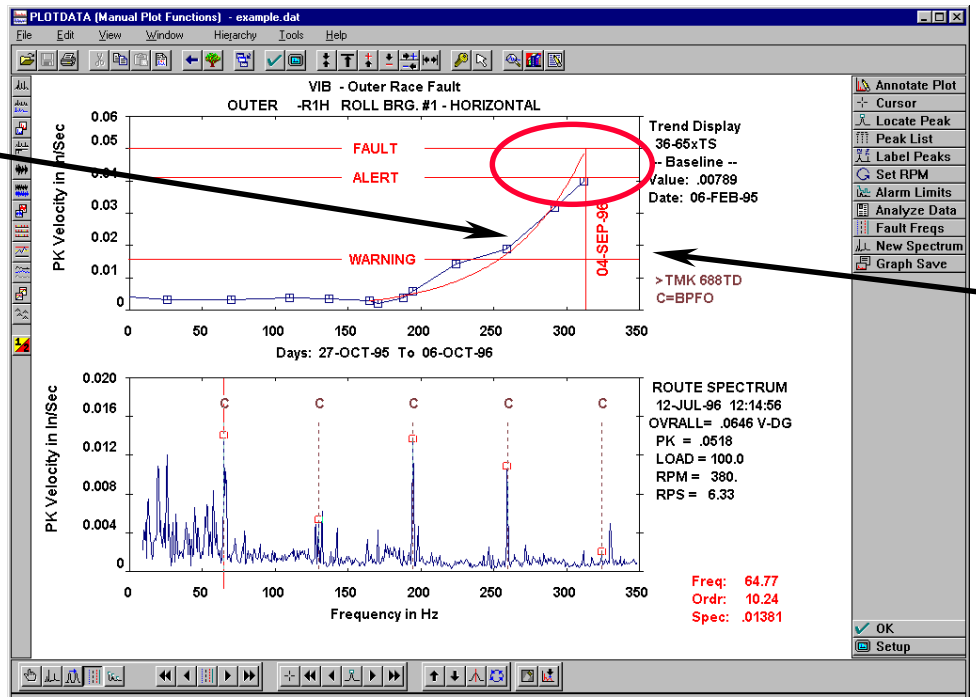


Step 6: Diagnose Nature of Fault



Step 6: Diagnose Nature of Fault

Trend shows rate of advancement for fault in question



Individual trend parameter covering suspect frequency range

Step 6: Automated Diagnosis

Date And Speed Analysis For (ALIGNMENT) Alignment Fault

Allowable Speed Difference Between Points (RPM): 30.

Allowable Time Interval Between Points (Seconds): 900.

POINT	DATE	TIME	DT(SEC)	RPM	RPM/FAC	RPM STEP	RPM-MEAN	FLAG
M1H	11-DEC-96	12:33	0.	3580.	3580.	.0	-6.0	
M1V	11-DEC-96	12:33	10.	3588.	3588.	7.8	1.8	
M2H	11-DEC-96	12:33	12.	3593.	3593.	5.4	7.2	
M2V	11-DEC-96	12:34	12.	3580.	3580.	-13.8	-6.6	
M2A	11-DEC-96	12:34	10.	3577.	3577.	-2.3	-8.9	
P1H	11-DEC-96	12:34	14.	3547.	3547.	-29.9	-38.8	S
P1V	11-DEC-96	12:34	10.	3592.	3592.	45.1	6.2	
P2A	11-DEC-96	12:34	12.	3601.	3601.	8.5	14.7	
P2H	11-DEC-96	12:35	12.	3590.	3590.	-10.9	3.8	
P2V	11-DEC-96	12:35	12.	3589.	3589.	-1.3	2.5	

Automatically Determine RPM across machine train

Statistical Analysis of RPM

Flag Suspect Readings

Step 6: Automated Diagnosis

Calculates Overall Severity

```
Diagnostic Summary For (FPMP      )  Feed Pump (Alignment Fault)
-------------------------------------------------------------
                Nspectr Knowledge Base Version:  V4.00
               Severity Score Basis:  Reference Envelope
                Diagnostic Severity Score (SEV):    28

          Data from  <01-Aug-96  15:15>  to  <01-Aug-96  15:16>
     KEY POINT(s)                  PROBLEM                          SEV--CERT
-----------------------------------------------------------------------------
P1H                  Looseness in structures restraining rotor       12-- 67
P2A P2V P2H          Significant impacting in equipment              10-- 99
P1H                  Shaft misalignment at coupling                   9-- 67
P1H                  Soft foot condition or faulty foundation         9-- 67
P1H                  Unbalance in rotor                               9-- 67
P1H                  Significant impacting in equipment               6-- 99
M1V M1H              Early impacting in equipment                     5-- 99
M2H M2V M2A          Early impacting in equipment                     1-- 99
```

Diagnosis Across Entire Machine Train

Multiple Diagnoses

Calculates Problem Severity

Calculates Certainty

Step 6: Automated Diagnosis

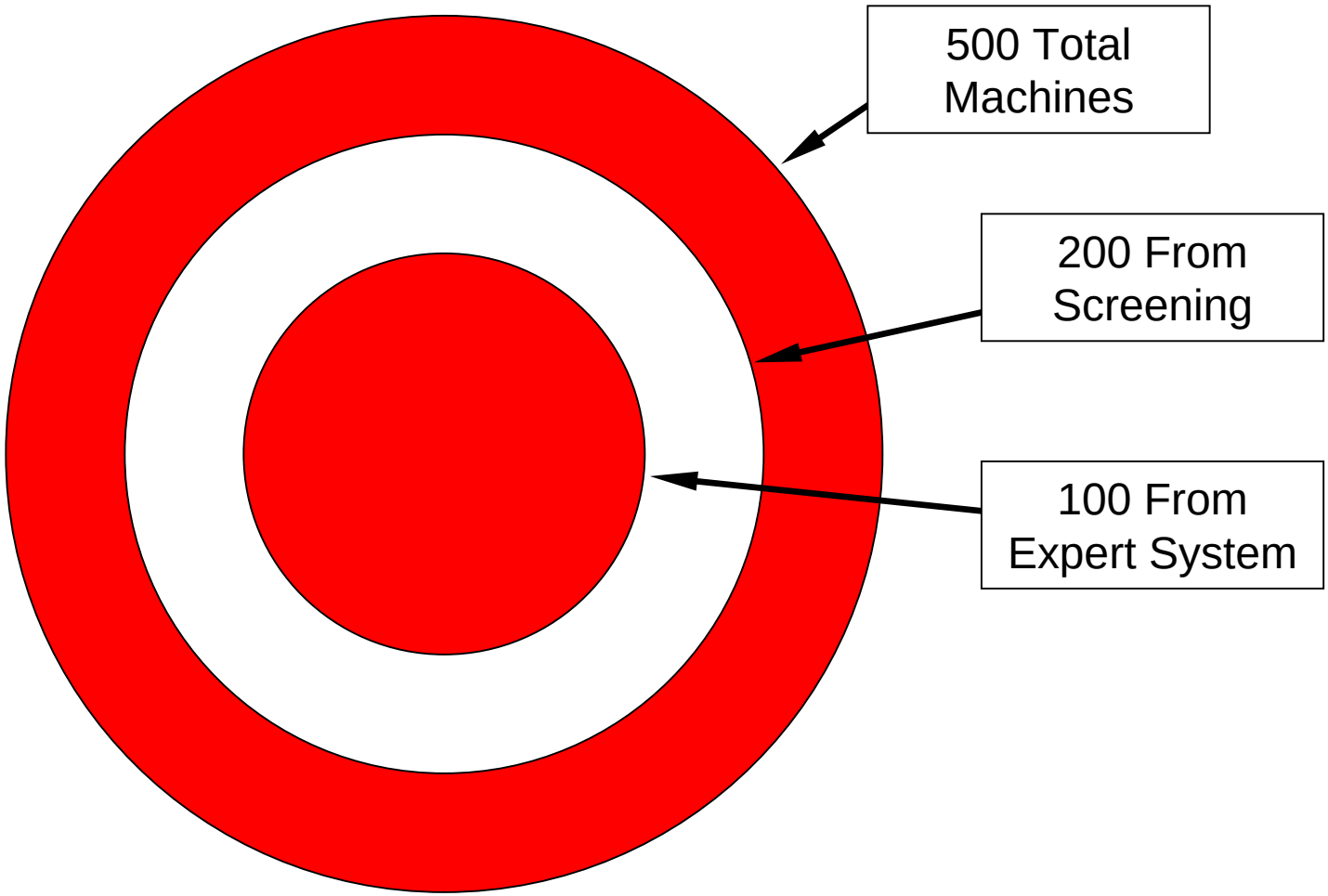
```
                         Diagnostic Rules For P2H
                         ------------------------
RULE  255
IF   Frequency components do not match predicted bearing frequencies.
AND  The waveform peaks show high levels.
AND  The waveform crest factor IS > The waveform crest factor limit *
     1.000.
THEN There is an indication of significant impacting occuring in the
     equipment.(100)
     Calculated Conclusion Certainty :100%
     Individual Rule Severity :  5
```

View Logic Tree for Diagnosis in Tutorial Mode

Step 6: Automated Diagnosis

- Purpose of Expert System is:
  - NOT to replace analyst, but…
  - to screen data to identify developing problems

Step 6: Automated Diagnosis



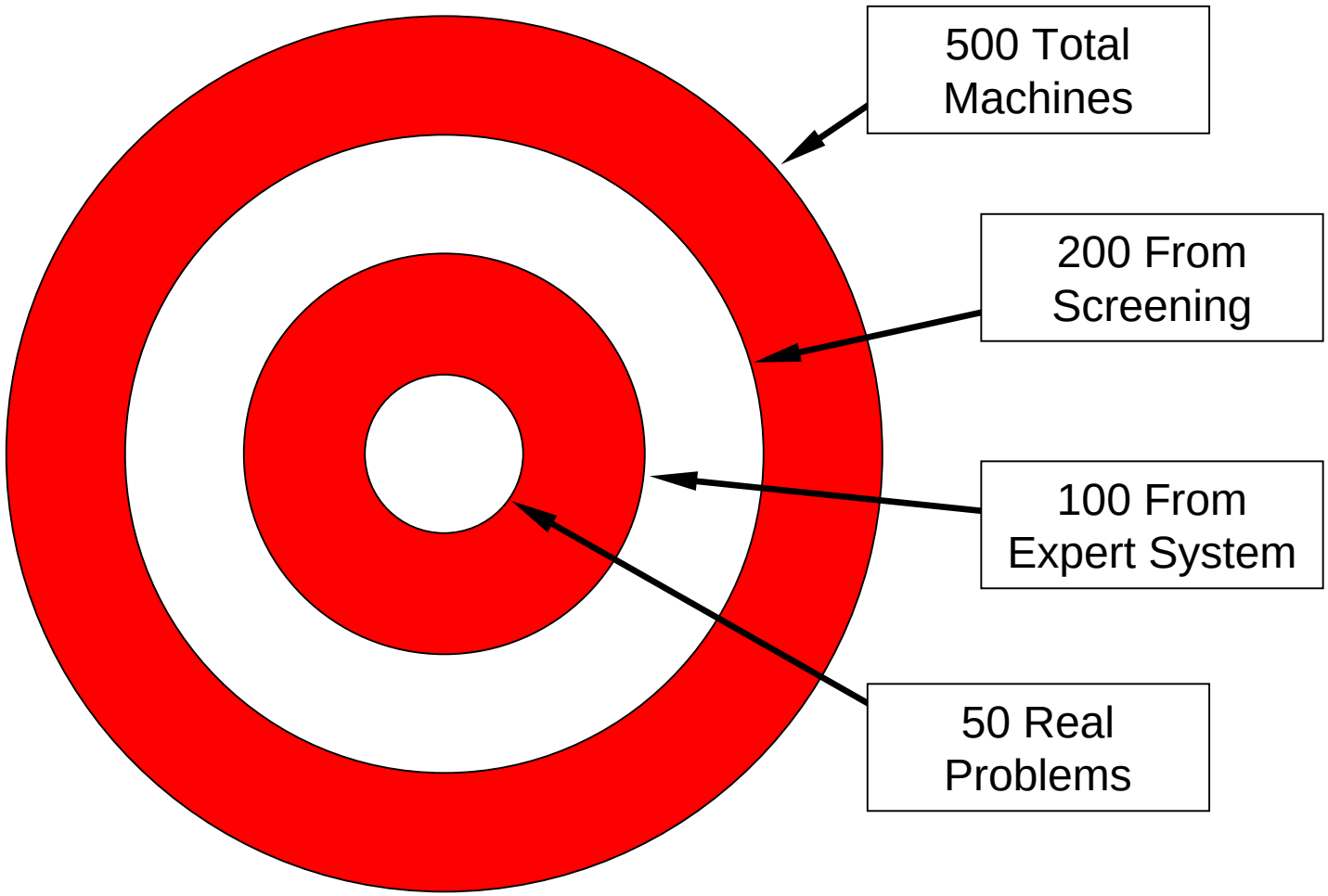
Need more Input?

- Periodic and on-line systems should provide the ability
  to collect additional diagnostic data:
    - increased resolution and/or frequency range
    - peak/phase measurement
    - order based analysis
    - time synchronous averaging

Advanced Analysis

- Transient Analysis
- Dual Channel Analysis
- Cross Channel Analysis
- Structural Analysis

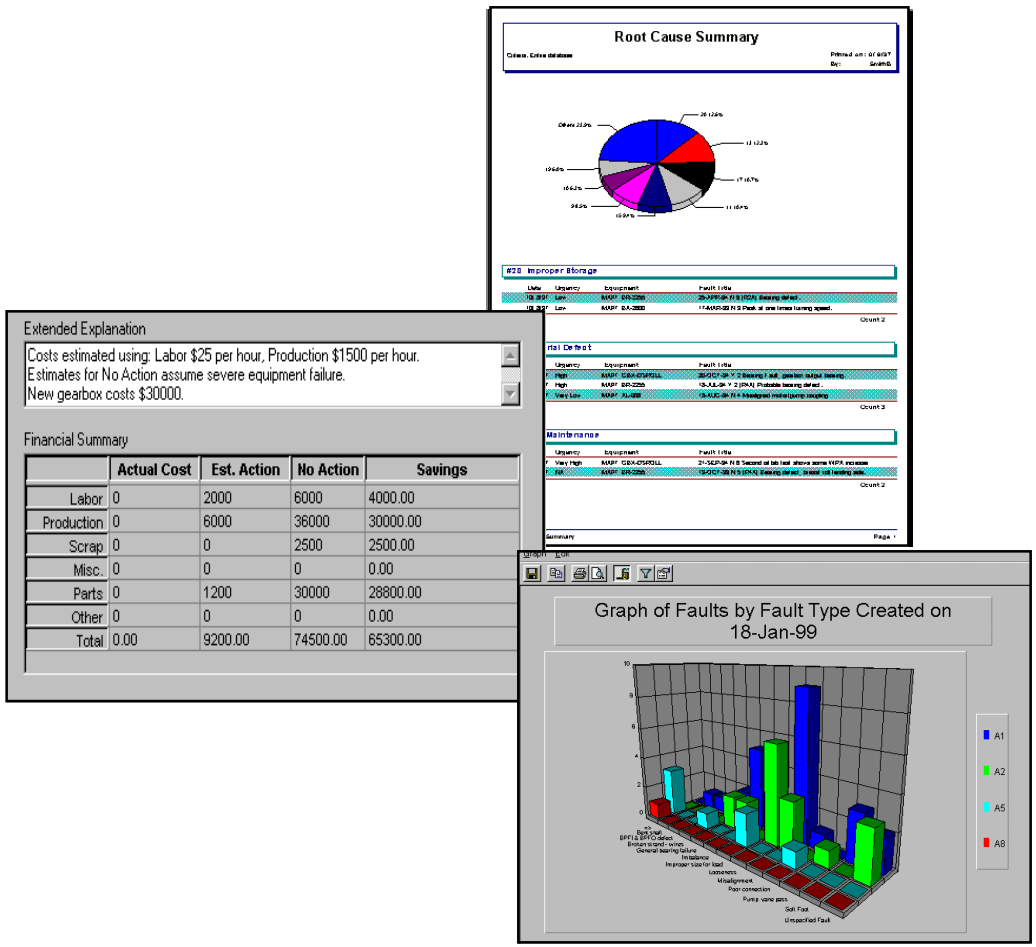
Step 6: Getting to the Real Problem



7) Document
Business & Maintenance Implications

Document:

- diagnoses
- recommendations
- accuracy
- reoccurring faults
- production gains
- cost savings
- financial impact



Vibration System Checklist

- **Periodic**
  - **Fast data collection**
  - **Analysis on Demand**
  - **Dual channel capability**
  - **Advanced gearbox & bearing analysis**
  - **Expandability**
  - **Expert System Software**

- **On-line**
  - **Parameter band alarming**
  - **Analysis on Demand**
  - **Dual channel capability**
  - **Connectivity - across network & other systems**
  - **Expandability**
  - **Expert System Software**

Integration of On-line & off-line system

Vibration Analysis